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some such element into the chitinized portion, and it should also be noted that the pupal wings of this suborder preserve a separate costal trachea.

If, then, we grant the antiquity of the costal vein, then *Permoraphidia* is seen to be in all points more archaic than existing Raphidioidea, and there is nothing to prevent our claiming it as in the line of their direct ancestry.

2

Suborder SIALOIDEA.

Family MARTYNOVIIDAE, n. fam.

(Figs. 5-7.)

Forewing with Rs pectinately branched; M fused basally with R; MA anastomosing with Rs for a space near its origin; Cu_2 absent or obsolescent; Cu_1 fused basally with R + M and giving off two long, diverging branches. All or most of the main longitudinal veins simple.

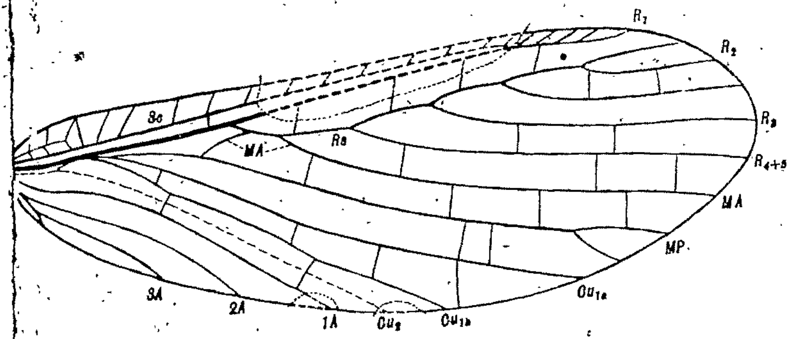

Fig. 5. *Martynovia insignis*, n. gen. et sp. Forewing. Specimen No. 5 23 (reverse), with apex placed to right for comparison with other forms. C, separate costal vein (cf. Fig. 1); MA, anterior and MP, posterior median vein. Rest of lettering as usual in Comstock-Needham System. Length of wing 12.4 mm. Suborder Sialoidea, family Martynoviidae. Lower Permian of Kansas.

This family is proposed for the reception of two interesting new genera, which may be distinguished as follows:

Costal space of medium width, with complete series of veinlets. Rs with five branches, forming a pectinate series. Three anal veins. .... Genus *Martynovia*, n. gen.
Costal space very narrow, with reduced series of costal veinlets. Rs with only four branches, forming a pectinate series more widely spaced. Only two anal veins. ....Genus *Martynoviella*, n. gen.

Genus *Martynovia*, n. gen.

(Figs. 5, 6.)

Forewing:—Costa slightly arched near base. Costal space moderately wide only near base, for the rest narrow. A single subcostal cross-vein present. Sc almost certainly ending on R_1 (the actual ending is missing in the fossil). Pterostigmatic area narrow, unchitinized, with regularly spaced veinlets, not crowded together. Inter-radial cross-veins (between R_1 and Rs) subparallel to costal veinlets, not strutted backwards and upwards as in recent Corydalidae. Rs proper arising at about one-third from base, five-branched, the branches forming a perfect pectinate series, with none of them branched or terminally twigged; to this series basally the free distal part of MA adds a sixth similar member. M arising from R near base and anastomosed for a very short distance with Cu_{1a}; it then runs free to a point about one-fourth from base, where it gives off the upwardly arching MA running to meet Rs, and also continues almost straight on as MP to the posterior margin at the level of the pterostigma; MP has a short terminal fork (this may not be a generic constant). Between MA and MP are some impressed spots which may represent ***nygmata*** as in recent Corydalidae, but the state of preservation of the wing is not good enough to make certain of this. Cu very weakly developed at base, just below R + M, and very soon dividing into an upwardly arching Cu_1, which anastomoses with R + M for a short space, and a free Cu_2 whose course lies in a furrow running to posterior margin and ending a little before half-way along it; the chitinization of this vein is obsolescent. Cu_1 branches below the anastomosis with R — M into an upper Cu_{1a} and a lower Cu_{1b}, both quite well chitinized; the former vein continues the anastomosis with M for a short distance and then runs freely, with a slight bend near its middle concave to Rs, and ends up without branching on the posterior margin at about three-fourths of the wing-length; Cu_{1a} diverges at first slightly and later rapidly from Cu_{1b}, ending up without branching at about half-way along the posterior margin, a little in front of Cu_2. Three anal veins present. Cross-veins few, weak and irregularly placed, except only the inter-radials, which are spaced evenly between the origins of the pectinate branches of Rs (except the last one), and the two cross-veins which connect Cu_1 with 1A; these latter are strutted on to

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Cu_{1b} so as to cause marked bends in the course of that vein, and both of them cross Cu_2 without a break.

Genotype:—Martynovia insignis, n. sp.

Horizon:—Lower Permian of Kansas.

This fine genus is dedicated to my good friend Professor A. Martynov, whose fine work on the Permian fossil insects of Russia has done so much to assist in our understanding of the evolution of the Pterygota.

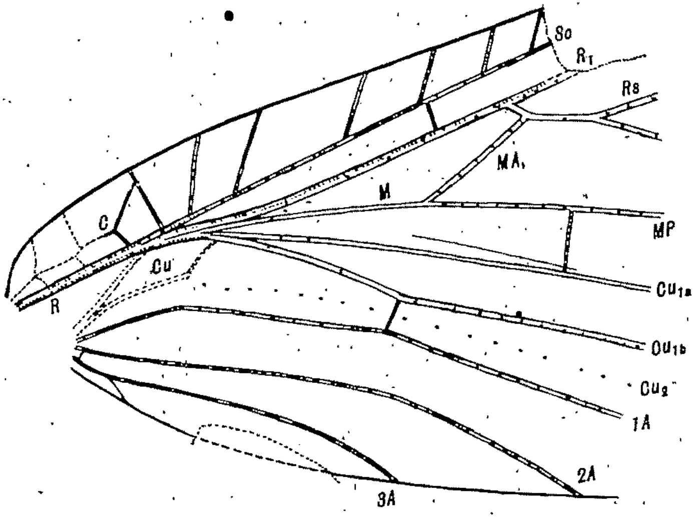

Fig. 6. *Martynovia insignis,* n. gen. et sp. Basal portion of forewing, further enlarged, to show anastomoses of main veins and course of obsolescent Cu_2. Lettering as in Fig. 5.

Martynovia insignis, n. sp.

(Figs. 5, 6.)

Total length of forewing 12.4 mm.; *greatest breadth* slightly over 4 mm. Characters as given in the generic definition. Of specific value only are the actual number of pectinate branches of Rs, the shape of the costa and the width of the costal space, the well-rounded apex of the wing, and perhaps the wide divergence distally between Cu_{1a} and Cu_{1b}. Points of interest not sufficiently brought out by the figures are the following:—The veinlets and cross-veins are for the most part very feebly chitinized, including those of the pterostigmatic region (shown too distinctly in Fig. 5); in the distal part of the wing, the position of most of the cross-veins is problematical, and those shown in the figure must be regarded simply as marking points where, under very careful lighting, some slight indication of their presence can be noted; in some cases, only the evidence of a slight bend in a main vein is present, indicating the point of attachment. The terminal fork of MP is weakly formed and may not even be of specific value. There is a marked variability in the depth of pigmentation of the veins, suggesting an irregularly alternating sequence of paler and darker patches, as is found in many recent Corydalidae. The main veins and some of the costal veinlets appear to have been sparsely hairy, as the sockets of these hairs can be made out, some dark and some pale. I am not able to satisfy myself completely as to the course of the obsolescent costal vein C, which is only at all clearly visible in its distal part. Nor can I trace with certainty the weakened basal portions of M and Cu, though in certain lights both of them appear to be indicated. Nor can I be quite certain of even the presence of the obsolescent Cu_2 (indicated by a dotted line in Fig. 5); in some lights nothing at all can be seen, while with other lighting arrangements one sometimes gets a distinct impression of a faint groove, and with others again one only makes out a faint indication of a row of weak sockets (as in Fig. 6). Perhaps in the actual wing the course of Cu_2 was indicated only by a very faintly impressed groove with weak hairs at intervals.

In Fig. 6, I have given an enlarged drawing of the basal portion of the wing, placing the base to the left as in Fig. 5 (in the actual specimen the apex is to the left). This figure will serve to show also the actual amounts of anastomosis between R, M and Cu_1 near the base, and also between Rs and MA further distad. The actual fossil is a reverse impression of the wing, and shows clearly that the general surface was very flat. Of the veins, only Sc, Rs and MP are concave, the others are definitely convex, including both branches of Cu_1 and all the anal veins. It is clear, in any case, that Cu_2 is obsolete or obsolescent. A comparison with *Permoraphidia* (Figs. 1, 2) will be found helpful in determining the homologies of the veins.

Type:—Holotype forewing, Specimen No. 5423 (reverse) in Yale University collection; type-counterpart missing. This wing, when received from Professor Dunbar, was only partially exposed, and I removed a considerable amount of rock from both anterior and posterior portions of it; unfortunately this was not an easy task, and a considerable amount of the costal margin came away with the removed rock, which was very soft. However, even so, the wing is now fairly complete.

The discussion of the relationships of this fine genus will be left until the end of the section on Sialoidea.

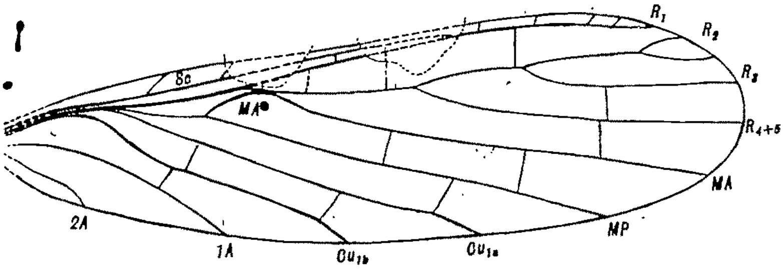

Fig. 7. *Martynoviella protohymenoides*, n. gen. et sp. Forewing. Specimen No. 5424 (obverse), with apex placed to right for comparison with other forms. Lettering as in previous figures. Length of wing 11.0 mm. Suborder Sialoidea, family Martynoviidae. Lower Permian of Kansas.

Genus *Martynoviella*, n. gen.

(Fig. 7.)

Forewing narrower than in *Martynovia* but with apex more rounded. Costal space very narrow, with few veinlets; pterostigmatic area very narrow. Rs arising at about one-third from base, with few branches widely spaced and pectinately arranged. MA arching up from its origin on M either to anastomose slightly with or just to touch Rs near its origin. Courses of MA and MP much as in *Martynovia;* both veins unbranched. Cu_2 obsolete. Both branches of Cu_1 fused basally for a short space with R + M; Cu_{1a} runs almost straight to a point a little beyond half-way along the posterior margin, while Cu_{1b} takes a slightly sigmoidal course, diverging distally from Cu_{1a} and ending up a little before half-way along the same margin. Only two anal veins present, the second being very short. Cross-veins few in number, but except for a few in the distal part of the wing, well-formed and easily made out in the fossil.

Genotype:—Martynoviella protohymenoides, n. sp.

Horizon:—Lower Permian of Kansas.

This genus, which is also dedicated to Professor Martynov, is evidently a specialized derivative from the same stem as *Martynovia,* n. gen., which it closely resembles in the general formation of the basal portions of Rs, MA, MP and Cu_1. The resemblance to Protohymenoptera may or may not be superficial, but certainly calls for further study. A discussion of its relationships is left until the end of the section on Sialoidea.

Martynoviella protohymenoides, n. sp.

(Fig. 7.)

Total length of forewing 11.0 mm.; *greatest breadth* 3.0 mm.

The specimen consists of the obverse impression only, with the apex to the left; for convenience of comparison, the figure is drawn with the apex to the right. The main veins are clearly marked and for the most part very darkly pigmented. almost black; R_1 is, however, somewhat paler, and the basal portion of M for some distance along MP is much paler. Evidence of the presence of small setae along the veins and around the margin of the wing can be found here and there, but for the most part the setae appear to be obsolescent or absent. Unfortunately the costal space is damaged in two places, so that the extent of the costal series of veinlets cannot be made out. One slanting veinlet can be seen a little distad from the level of the origin of M, and portion of another above and a little basad from the level of the origin of Rs. Sc itself is not present in the preserved distal portion of the costal space, and must be assumed to end either on the costa, or more probably on R_1, not far beyond half-way; beyond that are a few weakly formed costal veinlets in the narrow pterostigmatic region. An indication of a possible subcostal cross-vein appears a little before half-way. There would appear to be only two true inter-radial cross-veins with a possible third rather close to the origin of Rs. The anastomosis of MA with Rs is unfortunately damaged owing to loss of portion of the high ridge of MA just at the point of contact or junction; the actual anastomosis does not appear to have been as complete as in *Martynovia*. Well-marked cross-veins are distributed as follows:—one between R_3 and R_{4+5}, one just below it between R_{4+5} and MA, one about middle of wing between MA and MP, and a second further distad between the same two veins, one between MP and Cu_{1a} not far from distal end of latter vein, two between Cu_{1a} and Cu_{1b}, and one, just basad from the more basal of these latter two, between

Cu_{1b} and 1A. The extreme base of the wing is missing, and it is possible that it was a little longer and more petiolate than is indicated in Figure 7.

Type:—Holotype forewing (obverse), Specimen No. 5424 in Yale University Collection; type-counterpart missing.

Family CHORISTOSIALIDAE, n. fam.

(Fig. 8.)

Fairly large insects in which the wing has a complete series of costal veinlets of Sialoid type, the pterostigma is unpigmented, and the branchings of Rs and M are dichotomic, much as in Mecoptera. (Cu and anal veins missing.)

Here is placed, with some doubt, a rather fragmentary wing which appears to combine characters of both Sialoidea and Mecoptera, but is probably best referred to the former group. The fossil was probably a forewing, but even this cannot be stated with certainty.

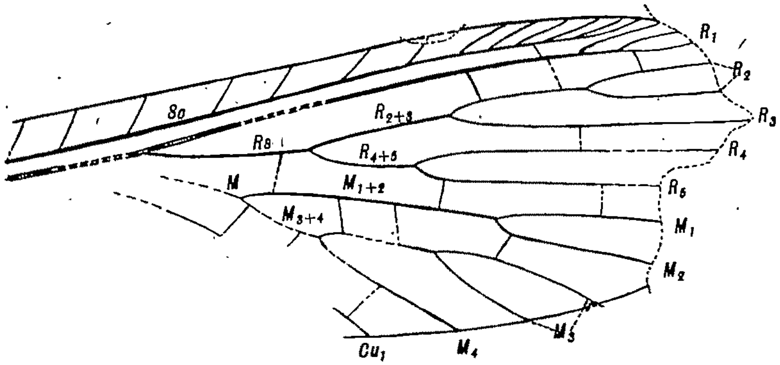

Fig. 8. ***Choristosialis enigmatica***, n. gen. et sp. Fragment of wing. Specimen No. 5425, drawn from combined obverse and reverse, with apex placed to right for comparison with other forms. Lettering as in previous figures except the branches of M, which are shown as usual in Comstock-Needham System, for comparison with the Order Mecoptera. Length of fragment about 11 mm. Suborder Sialoidea, family Choristosialidae. Lower Permian of Kansas.

Genus *Choristosialis*, n. gen.

(Fig. 8.)

Costal space of fairly even medium width, with a complete series of costal veinlets, which become more abundant and closely crowded together in the pterostigmatic region and are continued over on to the end of R_1 (which has three similar veinlets at its apex). Pterostigma not chitinized. Sc ending on costa very close to end of R_1. Rs dichotomically branched, there being five branches altogether, the extra one belonging to R_2. Origin of Rs well before half-way along R_1. Basal portion of M missing, but its branches preserved; of these there are five, two belonging to MA (or M_{1+2}) and three to MP (or M_{3+4}), the extra branch being on M_3. Only a slight trace of Cu_1 present, from which its actual form cannot be determined. Cu_2 and anal veins entirely missing.

Genotype:—Choristosialis enigmatica, n. sp.

Horizon:—Lower Permian of Kansas.

Choristosialis enigmatica, n. sp.

(Fig. 8.)

Total length of wing-fragment about 11 mm., representing a complete wing of about 13 mm. in length; *greatest breadth* (complete) 4 mm.

The state of preservation of this wing is, unfortunately, very poor. Seven fairly evenly spaced costal veinlets can be made out before the pterostigma, and five more closely placed together in that region, exclusive of the actual end of Sc; just beyond Sc are three closely placed veinlets at the end of R_1, inclusive of the end of that vein. A short cross-vein appears to connect Sc with R_1 below the pterostigma. Distally, between R_1 and Rs there are apparently three interradial cross-veins. A few cross-veins can just be made out in other parts of the wing. Setae were present along the main veins, as their sockets can be clearly seen in a number of places.

Type:—Holotype wing (obverse), Specimen No. 5425*a* in Yale University Collection; type-counterpart, Specimen No. 5425*b*.

The figure of the venation (Fig. 8) has been obtained by careful drawing of both obverse and reverse, and combining into one figure the evidence from both. The obverse specimen has the apex to the left.

RELATIONSHIPS OF THE LOWER PERMIAN SIALOIDEA WITH RECENT FORMS AND WITH OTHER GROUPS.

In order to facilitate discussion, the forewings of a representative of each of the two recent families of Sialoidea is here figured, viz., that of *Archichauliodes dubitatus* Walk. (Fig. 9) of the family Corydalidae, from New Zealand, and that of *Stenosialis australiensis* Till. (Fig. 10) of the family Sialidae, from Australia. Both the types figured are recognized as archaic types amongst existing Sialoidea.

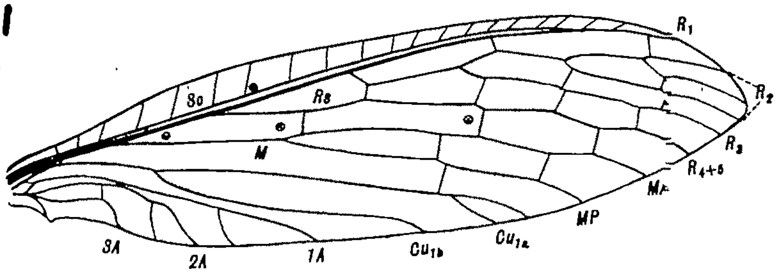

Fig. 9. *Archichauliodes dubitatus* Walk. Forewing. Suborder Sialoidea, family Corydalidae. Recent. Lettering as in previous figures.

We note first of all that, if we are correct in interpreting the limits of Rs and M in modern Sialoidea, neither the Corydalidae nor the Sialidae have any anastomosis between these two veins. They are, therefore, much more primitive in this respect than the Lower Permian Martynoviidae.

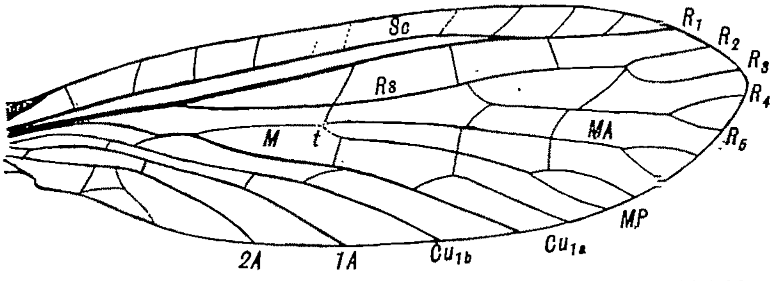

Fig. 10. *Stenosialis australiensis* Till. Forewing. Suborder Sialoidea, family Sialidae. Recent. Lettering as in previous figures.

Further, although in Sialidae there is an anastomosis between M and Cu_{1a}, there is none at all in Corydalidae, which are, therefore, on two very important characters, the most primitive of all. Apart from these characters, the two forms which invite the closest comparison are *Martynovia* and any of the more primitive and simply-veined Corydalidae, e.g., *Archichauliodes* and its relatives. Here we note a close correspondence in the form of the costal area (not always narrowed at the base as in *Archichauliodes*), in the complete series of costal veinlets, in the non-chitinized pterostigma, and, most probably, in the ending of Sc in R_1, though it should be noted that the Russian Permian genera have Sc ending on the costa. Disregarding the small fork at the end of MP in ***Martynovia,*** which quite probably has not even specific value, we note the correspondence in that there is no terminal twigging of the branches of Rs and M, and each branch proceeds evenly and simply to the wing-margin. In recent Sialoidea, three interradials are present normally both in Sialidae and in the more primitive genera of Corydalidae. The Martynoviidae approximate closely to this condition, but the direction of the cross-veins is still unspecialized. If our interpretation of the limits of Cu is correct, recent genera are more specialized than the Martynoviidae in not only having long ago got rid of all traces of the original Cu_2, but also in greatly narrowing the space between Cu_{1b} and 1A. In the anal area, the condition shown in Martynoviidae is much more primitive than that in recent Sialoidea, in which there is not only a clear development of a jugal lobe with supporting vein, but more complex curving and branching of the anal veins themselves.

We can therefore only conclude that the Permian Sialoidea now disclosed, as well as the Russian Permian genus *Permosialis,* are in no sense ancestral forms to our present-day types. They must rather be regarded as early specializations from the original stem of a very ancient group, while the main stem possessing fewer specializations in the region of Rs, M and Cu_1 continued to exist after these others had died out, and has evolved into present-day Sialoidea.

Turning next to the family Choristosialidae (Fig. 8), we find additional support for our view that the Sialoidea, and indeed the Neuroptera in general, were already highly specialized in Lower Permian times. For this is a type which it is really impossible to assign to either the Mecoptera or the Neuroptera until we have a more complete specimen to guide us. We may note that Comstock claims the dichotomic mode of branching as more primitive than the formation of a pectinate series, and there is much to be said for this view. The branching of Rs in Sialidae is in any case dichotomic, not pectinate, and the pectinate types in modern Sialoidea are confined to the larger forms of the family Corydalidae. The fact that M is never pectinately branched in any form, and Cu_1 only in a few heavily veined types amongst the Corydalidae (e.g. in *Corydalus, Protohermes,* etc.) is also a strong argument in favour of the primitiveness of the dichotomic mode of branching. In this respect, the Mecopterous wing is more primitive than the Neuropterous. For a comparatively large form, the venation of *Choristosialis* appears to be very primitive indeed, and it is much to be hoped that further exploration of the Lower Permian Kansas beds may yield a more complete specimen of it. At present, we cannot go beyond the statement that, if this genus proves to be as generalized as its present fragment leads us to imagine, then we may find in it a type annectant to the two orders Mecoptera and Neuroptera, the connection being between the Meropoidea or Protomecoptera on the one hand and the Sialoidea on the other.

A further interesting point arises when we consider by itself the highly specialized genus *Martynoviella* (Fig. 7). There is here, surely, something more than a purely chance resemblance to Protohymenoptera. While it can scarcely be doubted that this genus is Sialoid, the strongly formed veins and cross-veins, with the obsolescent chaetôtaxy, the general scheme of venation and the curious arrangement of the cross-veins, strongly suggest the possibility of an affinity between the two orders. And if, as may be possible (though I cannot accept Carpenter's supposed proof of it, of which more later), the Protohymenoptera are descended from Megasecoptera, then we may also have to reconsider Handlirsch's view that the Neuroptera are similarly derived.

Suborder PLANIPENNIA.

Family PERMOBEROTHIDAE, n. fam.

Forewing with Rs arising close to base of wing. No anastomosis between Rs and MA. A short anastomosis near base between M and Cu_1. The original concave Cu_2 present, very weakly chitinized, but carrying a complete set of setae. Three anal veins present. Veins very hairy.

This family is allied to the Palaemerobiidae Mart. from the Russian Permian, with which it agrees in the very hairy veins, in the lack of anastomosis between Rs and MA, in the presence of Cu_2 and in possessing three anal veins. Rs, however, arises much closer to the base, and there is a marked anastomosis between M and Cu_1 which is absent in Palaemerobiidae, where these two veins only make contact at a point.

The two families might be united later on when fuller knowledge has been obtained of the genera represented, by a marked modification of Martynov's original definition (1928, p. 86) and a relegation of a number of his family characters to the position of generic characters for *Palaemerobius* Mart.

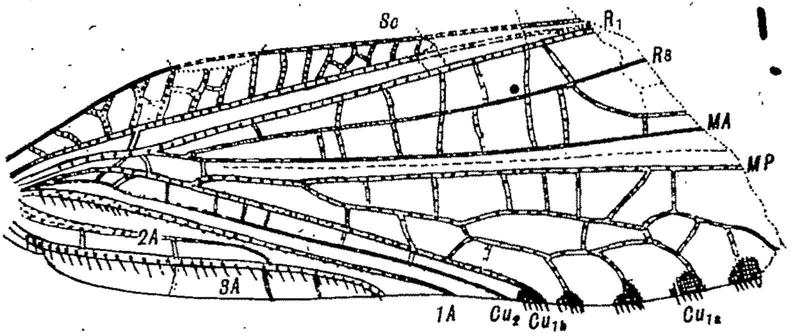

Fig. 11. *Permoberotha villosa*, n. gen. et sp. Forewing. Specimen No. 5426 (reverse). Lettering as in previous figures. Length of preserved portion of wing 6.3 mm. Suborder Planipennia, family Permoberothidae. Lower Permian of Kansas.

Genus *Permoberotha*, n. gen.

(Fig. 11.)

Forewing:—Shape long and narrow (apical portion missing). Veins very hairy, the sockets warty, mostly darkly pigmented and very clearly impressed in the fossil. Costa strongly arched near base; the costal space at first very narrow, then rapidly broadening out up to a level a little beyond that of origin of Rs, then rapidly narrowing again. No branched *vena recurrens* present, but the first two or three costal veinlets directed backwards. One subcostal cross-vein between Sc and R just before origin of Rs. Rs arising close to base and dividing almost at once into two very long and slightly diverging branches which appear to be connected with one another and with R_1 by means of numerous weakly formed but hairy cross-veins; distal courses of these two branches missing in the fossil, but there is some slight indication of further branching from the upper one. A marked radio-median groove separates the region of Rs from the region of M (as in recent Hemerobiidae). M very weak at base, but apparently distinct from R. Below the level of the origin of Rs, M anastomoses with Cu_1 for a length of a cell and a half; just above the point where it leaves the anastomosis with a slight upward bend there is a weak connecting cross-vein with R_{4+5} close to its origin. A little further distad, M divides into its two main branches, MA and MP; the former runs for a long distance without branching, at first parallel to R_{4+5} and later slightly diverging from it; MP soon divides and sends numerous branches to the posterior margin. Cu very weak at base up to its primary fork, which takes place a little basad from the level of the subcostal cross-vein. Cu_1 arches up to anastomose with M as already described, leaving M again at the level of the first forking of Rs; it runs straight to the posterior margin and is very hairy, carrying a double series of strong sockets. Whether any of the branch veins running to the posterior margin beyond the straight Cu_1 belong to this vein or not cannot be determined, though possibly the first two forks beyond it properly belong to Cu_1 and not to MP. Cu_2 runs straight below Cu_1, converging slightly towards it distally; it is a narrow, weak vein, almost obsolescent basally, but carries a row of strong hairs. 1A a strong, straight vein running parallel and close to Cu_2 and furnished with many setae. 2A a shorter, slightly curved vein, ending up rather weakly on 3A well before its end. 3A a long, slightly curved, thick vein, converging towards 1A distally, and ending up not far from it; this vein carries a row of stout hairs which were evidently directed posteriorly, as not only their sockets but the actual hairs are impressed on the rock. The posterior margin below the anal veins does not carry hairs, but the ends of the branchlets from Cu_1 and MP are surrounded by patches of dark pigment, with bunches of strong hairs developed on the margin included therein (as in the recent Australian species *Spermophorella maculatissima* Till.).

Genotype:—*Permoberotha villosa,* n. sp.

Horizon:—Lower Permian of Kansas.

Permoberotha villosa, n. sp.

(Fig. 11.)

Length of fragment of forewing 6.3 mm., representing a total wing-length of probably at least 9 mm. *Greatest breadth* of preserved portion 2.0 mm., which is probably also the greatest breadth of the complete wing.

This fossil is remarkably well-preserved, and it is unfortunate that only the reverse impression has been saved and that the distal portion of that is missing. The most striking character of the wing is the abundance of strong hairs, probably for the most part long and erect, as in *Trichoma* Till. (subgenus of *Berotha*) or *Spermophorella* Till.; but along 3A and the basal part of 1A the hairs are directed posteriorly, as is proved by their actual preservation on the rock in that direction. In other parts, only for the most part the warty sockets of the hairs are preserved, though here and there may be seen the impression of a hair *in situ* or broken off. The number of sockets is very large, as in *Trichoma,* much greater than in either *Palaemerobius* or *Spermophorella.* Many of the cross-veins carry hairs as well as the main veins, but they are mostly weakly chitinized; in Figure 11 I have indicated their courses by following the lines of sockets shown in the actual fossil. A few of the costal veinlets appear to have had weak connecting cross-branches, especially in the broadest part of the costal area.

Type:—Holotype forewing, Specimen No. 5426 (reverse, with base to left), in Yale University Collection. Type-counterpart missing.

In his "Types of Permian Insects, Part III" (this Journal, 23, 1907), on p. 169, at the end of the family Delopteridae, Sellards describes briefly, without a figure, a genus and species *Urba punctata* which may have been a Planipennian and might even be the same as the species here described. He says that the genus *Urba* "is characterized by a slender elongate anal area traversed by three or four veins. The wing membrane has a punctate appearance, due probably to the presence of short spines bordering the veins." The length of the wing is given as 9 mm., breadth 3 mm. Type No. 1117 in Sellards' Collection. It is quite impossible to say anything definite about this insect without seeing the type.

RELATIONSHIPS OF THE LOWER PERMIAN PLANIPENNIA WITH OTHER FORMS.

The most obvious comparison to be made between *Permoberotha* and other types of Planipennia is with the Russian Permian genus *Palaemerobius* Mart. (Fig. 12). Although the horizon of the Russian genus is probably higher than that of the Kansas form, it would, I think, be fair to claim *Palaemerobius* as the more primitive of the two, not only because of the absence of anastomoses between its main veins, but also because the chaetotaxy of the wing is much more normal, closely resembling that of *Spermophorella.* It should be noted that a correction is needed in the interpretation of the venation of *Palaemerobius* as given by Martynov, who appears to have failed to recognize the existence of the true Cu_1, though it is shown in his figures unlabelled. Consequently, the true Cu_{1b} (labelled thus in Fig. 12) has been called by him A_1, while Cu_{1a} is simply labelled Cu; also Martynov's veins A_2, A_3 and A_4 should be 1A, 2A and 3A respectively, and are so labelled in my Fig. 12. A comparison of both fossils with *Permoraphidia* (Fig. 1) should settle this question without any doubt.

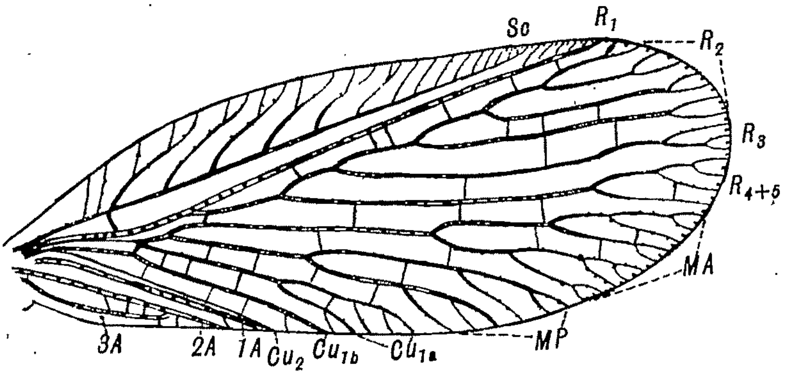

Fig. 12. *Palaemerobius proavitus* Mart. Forewing, adapted from Martynov, with lettering of veins altered. Suborder Planipennia, family Palaemerobiidae. Permian of Russia.

It must follow, from our study of these two Permian forms, that what may be broadly termed "Hemerobioid" types, but without any specialized anastomosis of MA with Rs, must go back well beyond the Lower Permian. For it cannot be for a moment argued that *Permoberotha* is by any means a primitive form. Consequently the ancestors of the Planipennia, as of the Sialoidea, must be looked for in the Upper Carboniferous or even in beds older than these geologically.

It is interesting to note that, when I received recently for study a new species of Berothid from Northern Australia, I was so impressed with the primitive formation of the forewing that I thought for a moment that I had found a living representative of the Permithonidae! This idea was only dispelled when I came to study the hindwing, which, in the

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Berothidae, is specialized in the region of Cu_1, which develops a long series of short veinlets running to the posterior margin of the wing. The formation shown in the forewing appears to me to indicate how this may have been brought about by capture of some of the branches of MP.

Unless, of course, the hindwing of one of the Permian fossils can be found, it will never be possible to state definitely whether these forms are true Berothidae or not. I consider, however, that there is no inherent reason why they should not be so. Martynov mentions especially the "dissimilar arrangement of the terminations of Sc and R" as a reason why *Palaemerobius* cannot be considered as allied to *Spermophorella*. However, it is just in the family Berothidae alone of all Planipennia that it is impossible to define the type of ending of Sc; in other words, the Berothidae are the only modern family of Planipennia in which the ending of Sc has not become fixed into one form or another! Therefore, even though *Palaemerobius* differs in this character from *Spermophorella* (in which Sc ends on R_1) it does not differ from the family Berothidae, and could rightly be included within it. It is true that modern Berothidae appear to have entirely lost the original Cu_2, but I do not find any other characters in the region of M and Cu in which they differ from the Permian genera, provided that my interpretation of the limits of Cu and the anal veins is accepted.

The excessive hairiness of *Permoberotha* is actually paralleled by the Australian subgenus *Trichoma* Till. of the genus *Berotha,* in which also Sc definitely ends on the costa and not on R_1. The form of the costa and costal veinlets is closely similar in both, except that there is an incipient returning vein in *Trichoma.* I must confess that I can see no valid reason why the genus *Permoberotha* should not be regarded as a representative of the ancestral stem of the Berothidae, and particularly of *Berotha* and *Trichoma.*

The close resemblance of the forewing of recent *Trichoma* to the Upper Permian Permithonidae in venation offers us a further field of study. Here we may start off with the Russian Permian genus *Sialidopsis* Zal., originally placed by Zalessky in the Sialoidea, but now admitted by Martynov to be a true Planipennian. Here we may note that Sc still continued to end up on the costa, and it is only in the later and more specialized types from the Upper Permian of Australia that Sc ends up on R_1. Further, in *Sialidopsis* we find the three specially strutted inter-radial cross-veins which are found also in *Permithone* and in recent Berothidae.

It seems fair to conclude that Berothidae and Ithonidae must be closely allied, and that their common ancestor is to be found amongst the Lower Permian stock of which *Permobertha* was a representative. On the totality of characters, it would now appear as if the Berothidae are the oldest existing family of Planipennia, with Ithonidae, Dilaridae and finally Hemerobiidae representing one line of evolution, while Prohemerobiidae and Psychopsidae were specialized side-branches. The Sisyridae would appear to have MA attached to Rs (certainly so in the hindwing, and highly probably in the fore) and must therefore be a specialized side-branch distinct from both Dilaridae and Hemerobiidae. The position of the Coniopterygidae is still as much a mystery as ever, there being no close connections between these highly reduced forms and other Planipennia, either fossil or recent.

In conclusion, we see that all three suborders of Neuroptera were represented in the Lower Permian by distinct and comparatively highly specialized types. A study of these types indicates clearly that the common ancestor must have been a form without any specialized anastomoses of the main veins, i.e. with MA running free from Rs entirely and with MP free from Cu_1. It must also have had an original concave Cu_2, lightly chitinized but still quite distinct. The original type of branching of M and Cu_1 was evidently dichotomic, and that of Rs probably the same. The costal series of veinlets was probably complete and the pterostigma not chitinized. Such a type appears to show an approximation towards the Protomecoptera or Meropoidea amongst the Mecoptera, but it seems highly probable that the common ancestor of the two orders Mecoptera and Neuroptera was neither truly Meropoid nor truly Sialoid, but some form more primitive than either. Whether Handlirsch was right or not in claiming a direct descent for the order Neuroptera (his three orders Raphidioidea, Megaloptera and Neuroptera s. str.) from the Paleodictyoptera, we do not yet know. The same author claims that the Mecoptera were descended from Megasecoptera! If there is one thing that appears certain from our study of fossil Holometabola in the Lower Permian, it is that the two orders Mecoptera and Neuroptera must have come from a common stem which was probably also the first holometabolous type. My own feeling is very strongly that this type must have combined in itself the more archaic characters of both Meropoidea and Sialoidea. I am not able at present to recognize such an ancestor as having been a true Paleodictyopteron; it could equally well be claimed that it was a Protorthopteron or even a Protoblattoid!

In any case, it appears certain that the Neuroptera as understood in this Part never gave origin to any other groups except the three which already existed in the Lower Permian. Raphidioidea, now reduced to a mere remnant, may have been the equal of Planipennia in numbers in Lower Permian times. Sialoidea, now only a small group with two families, were probably much more abundant than either Planipennia or Raphidioidea, though almost certainly not as abundant as Mecoptera. Only the Planipennia have had any marked degree of success and are to-day a moderately strongly represented group chiefly suited to live in dry climates. The Mecoptera, on the other hand, already fairly abundant in Lower Permian times, continued to progress right up to Jurassic times, though since then they have declined to very small numbers. This order without doubt gave origin to the Protodiptera in Upper Permian times and thence to the Diptera, while in another direction, probably in the Trias, it also gave origin to the common stem-form of the Trichoptera and Lepidoptera.

In addition, the discovery of *Martynoviella* (Fig. 7) may perhaps open up further possibilities concerning the origin of the Hymenoptera from some early Sialoid type, and suggests that further comparisons with the Protohymenoptera are also worth making.

Red Hill,
  Canberra, F. C. T.

THE PETROLOGY AND STRUCTURE OF THE SALISBURY-CANAAN DISTRICT OF CONNECTICUT.*

WILLIAM M. AGAR.

The towns of Salisbury and Canaan lie in the northwestern corner of Connecticut along the New York and Massachusetts boundaries, in a district which has interested geologists since the days of Ebenezer Emmons and the beginning of the Taconic controversy.

The writer has been studying the formations of western Connecticut for some years past. He has referred in previous papers to the general problems of the district and to the published opinions of others. The purpose of this paper is to present the results of this study for the designated area only (Fig. 1), with no more reference to the regional problems than is essential. The area is the southern continuation of the Berkshire Hills and Housatonic Valley of Massachusetts and is a broad, undulating lowland of marble bounded on the east and southeast by the schists and gneisses of Canaan Mountain, the Norfolk upland, and Sharon Mountain; on the west by the schists of the Taconic Range and Indian Mountain. The many steep schist ridges that rise above the lowland, such as Tom's, Falls, and Prospect Mountains, reach elevations perceptibly lower than those of the bounding uplands. The bed-rock formations are all metamorphic. They consist of pre-Cambrian schists and gneisses, undifferentiated on the accompanying map; a series of schists of undetermined age; a quartzite and an arkosic gneiss unconformable upon the pre-Cambrian; a variably dolomitic marble probably of Cambrian and Ordovician age; and a schist with a variety of structural and petrographic types, that overlies the marble. This schist has previously been called the Berkshire schist but since that is a comprehensive name which includes a number of rocks that may not be related, the name Salisbury schist will be applied to it in this locality.

DESCRIPTION OF THE FORMATIONS.

Pre-Cambrian gneisses and schists. The upland, both east and south of the area considered, is composed of granitoid gneisses that have penetrated the older pre-Cambrian, the Grenville, metamorphics. The resulting complex[1] has been thrust west and northwest over the marble lowland and is intruded by granite younger than the marble and schist.

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Schists of undetermined age. These rocks form the large synclinical mass of Canaan Mountain and extend south and east (off the accompanying map) as long, intermittent bands nearly, if not quite, all the way to Long Island Sound. They have been previously mapped as the Berkshire Schist but since, as stated above, that name appears to have been used too comprehensively, the writer prefers to leave them unnamed for the present. They have many points of similarity with some of the Grenville inclusions in the gneisses and may actually include a number of separate formations.

The schist that forms Canaan Mountain lies above the marble of the lowland and together with it forms a large, somewhat distorted synclinal structure. Its position above and its apparent conformity to the marble, suggest that it is the same rock, and in the same position, as the Salisbury schist further west. But there are at present certain objections to this interpretation. The boundaries of the southward continuation of this formation and other similar but isolated formations are completely conformable to the older composite gneisses and seem at times to grade into them without any perceptible break. This is characteristic of the Grenville schists, but it is difficult to reconcile with the supposed younger age of the rocks in question. Furthermore, the contact between the Canaan Mountain schist and the underlying marble, while usually hidden, is exposed at one place along the southern face of the mountain and, between the typical representatives of the two formations there lies a cataclastically deformed microcline gneiss. The origin of this rock is obscure. It may represent a coarse arkose or a granite sill intruded along the contact. It any case it has been so greatly deformed that the lower part is a blastomylonite made up of red-brown biotite, quartz, microcline, and oligoclase, with apatite, leucoxenized titanite, pyrrhotite, and zircon as accessories. Ten yards above the rock is still strongly deformed and holds fifty per cent of microcline. This indicates the possibility that a thrust zone separates the schist from the marble. If this is so it is the continuation of the overthrust that bounds the marble lowland on the east and southeast but which is impossible to follow eastward into the gneisses of the Norfolk upland. This is an interesting possibility which requires further study. The rock beneath the deformed zone is made up almost wholly of actinolite, diopside, calcic plagioclase, biotite, garnet, titanite, and scapolite with a little calcite, magnetite, and very rare tourmaline. It was originally a marble that has been much more thoroughly silicated than is usually the case and the minerals present indicate some contact metamorphic action but there is no visible intrusive to account for it.

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[1] For details see: Proposed Subdivision of the Becket Gneiss of Northwest Connecticut . . . . Agar, W. M., this Journal, 17, 197-238, 1929.

Another reason for placing the Canaan Mountain schist in a series separate from the Salisbury schist is that the composition and micro-structure of the two are different. Nevertheless, these differences are not so great as to remove the possibility that the rocks were originally different sedimentary facies of the same formation. The prevailing type of the Canaan Mountain rock is a quartz, oligoclase or andesine, biotite, garnet, and sillimanite schist with occasional bands containing microcline. Staurolite is rare. The accessories are apatite, zircon, and magnetite. The biotite is usually a yellow-brown, moderately pleochroic type with strongly marked cleavage but with few pleochroic halos. Occasionally it is strongly pleochroic, red-brown, and is full of pleochroic halos. Sometimes it is greenish brown. The plagioclase frequently contains irregular areas of low refracting feldspar which can sometimes be determined as microcine. These areas are often barely discernible, under high magnification, as a mottling in the plagioclase, but more often the introduced character of the potash feldspar is apparent because of the way it enters along contacts and spreads out into the plagioclase. When the rock contains microcline as an original recrystallization mineral there are also patches of myrmekite that embay it. Introduced quartz is fairly common but tourmaline is rare. Some areas of this same rock further south contain bytownite as well as the feldspars here noted. This is invariably partly destroyed by the later potash feldspar. It is not possible to explain the relationships between these feldspars at present. They are noted here merely to distinguish these rocks from the Salisbury schist described in detail further on. The garnet in this rock is always in small anhedral or subhedral fragments. It is frequently broken or badly cracked with partially granulated edges and sometimes it is irregularly replaced by fibrous biotite.

This fact, coupled with the universal cataclastic deformation of the characteristic crystalloblastic structure of the rock, indicates a deep-seated retrogressive metamorphism. The retrogression is not far advanced and the only sign of strong deformation subsequent to recrystallization is in the microcline gneiss zone described above.

The quartzite and gnessoid arkose. These rocks occur in isolated areas along the eastern and southern edges of the overthrust block of gneiss. They either lie unconformably upon the pre-Cambrian rocks or they form ridges in the marble valley as at Rattlesnake Hill in Connecticut and other hills in southwestern Massachusetts. The problem of their age and relation to the other rocks is a complicated one.[2] They are believed to correlate, in part at least, with the Poughquag quartzite of New York State.

The marble. This is the rock which has been called the Stockbridge limestone. It is so designated on the accompanying map. This correlation is regarded as probable but it is not proved. No attempt is made here to distinguish the dolomitic from the calcic phases. Reference may be had to the map prepared by T. Nelson Dale[3] for the distribution of these types, though they probably do not occur in such regular belts as he has indicated. The rock is pure enough in places to support a considerable quarry industry but it usually contains disseminated phlogopite, muscovite, magnetite, pyrrhotite, and quartz. Many parts contain diopside and tremolite and a variable amount of feldspar, usually a calcic plagioclase, but sometimes microcline. The eight hundred foot closed contour on the map (Fig. 1) immediately east of Housatonic River and about one-half way between Falls Village and Canaan, marks the southern end of a ridge composed of marble almost wholly intruded and replaced by quartz. Parts of it contain three to four inch long crystals of tremolite, many of which radiate from a common center like the spokes of a wheel. This area is irregularly shaped but extends in a northeasterly direction to Housatonic River and there ends abruptly.

Just north of Canaan there is a low ridge that does not show on the accompanying map, composed of irregularly silicated and silicified marble containing disrupted beds of quartz-diopside rock which weather out as prominent bands two feet wide and sometimes stand three or four feet above the marble. The rock in this belt shows strong cataclastic deformation.

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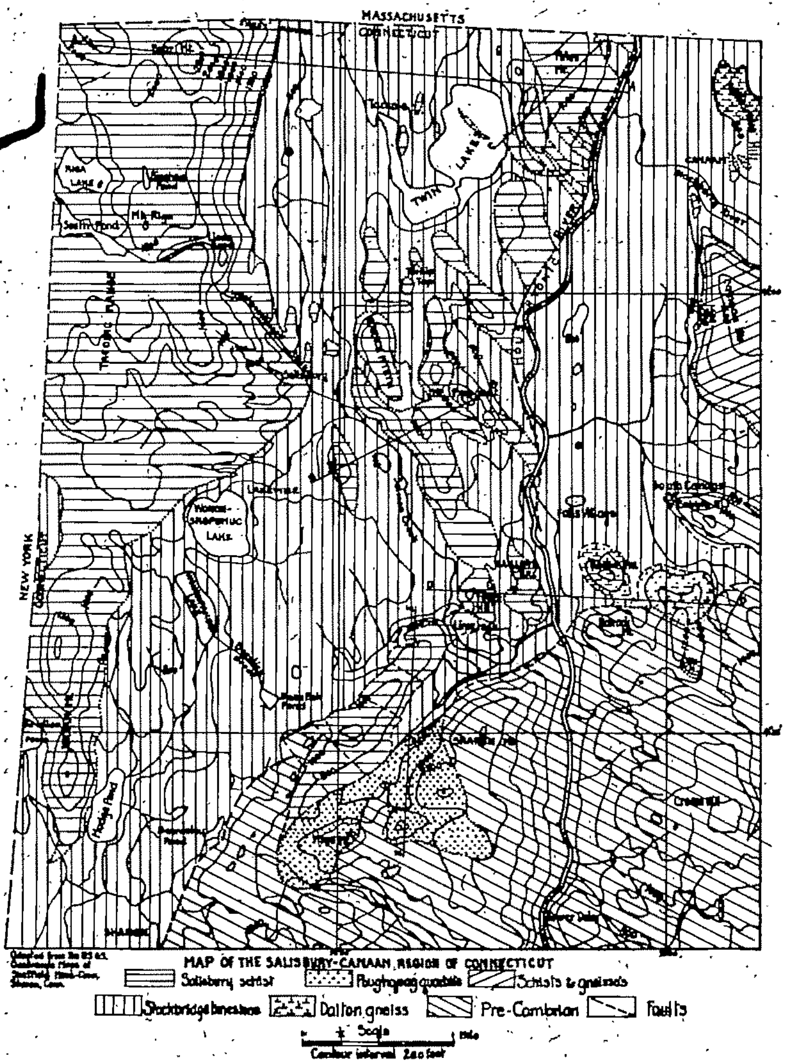
[2] For details see: The Quartzite of Rattlesnake Hill, North Canaan, Conn. Agar, W. M., this Journal, 21, pp. 409-421, 1931.

[3] The Lime Belt of Massachusetts and parts of Eastern New York and Western Connecticut, U. S. G. S. Bull. 744, Plate III, 1923.



MAP OF THE SALISBURY-CANAAN REGION OF CONNECTICUT

The amount of deformation in the marble is difficult to determine. Glaciated outcrops show considerable intricate folding of the strata on a small scale which can be traced by the bands of impurities. A well-exposed section at the falls in

Housatonic River at Falls Village indicates how much crumpling the rock has undergone. Most of the marble area is, however, covered by drift, and small outcrops are difficult to interpret because of their weathered condition and the simulation of bedding planes by solution along joints.

Only where the marble is folded together with the schist can the structure be definitely interpreted. The geological sections accompanying this paper (Fig. 9) indicate the results of the study of these sections and show that the rock is complexly folded and that individual beds, if they could be recognized, would be found to be repeated many times.

The contact between the marble and the Salisbury schist. The composite ridge between Twin Lakes and Housatonic River, known as Tom's and Miles Mountains, is composed of marble that grades through a calcareous, ferruginous schist into the Salisbury schist. The high points of the ridge are mostly schist but an impure, schistose marble rises to within one hundred feet of the top and forms a steep west-facing cliff at the north end of Tom's Mountain. The ridge (Structure section C-C, Fig. 9) is formed of three north-plunging synclines overturned towards the west with a north-plunging anticline at the extreme northeast end.

A good, though discontinuous, section along the south and southeast base of the ridge is exposed in a series of small railroad cuts. These show a repetition of schist and marble outcrops. Two of the three westernmost marble belts continue north to join the broad marble lowland northwest of the ridge. The central one of the three wedges out before the highest point in Tom's Mountain is reached. A coarse-grained schist lies immediately above this band and, since this is not the normal succession for the region, it is believed that a small thrust cuts out the marble. The rest of the bands of marble shown on the map disappear before the higher part of the ridge is reached. They represent repetitions of the schist and marble near the contact between the two formations brought about by tight isoclinal folding. These disappear further north on the hill because both the greater topographic elevation and the northward plunge of the folds brings the higher schist beds to the surface. An even finer scale alternation of the marble and schist which represents interbedding near the contact is visible in many parts of the railroad section. Much of the lower part of the schist is calcareous and ferruginous (Fig. 2) and the marble next to it contains considerable strained quartz, plagioclase, biotite, apatite, magnetite, and some graphite. The contact between the two rocks in this region is clearly gradiational. Similarly the small schist ridges south and east of Taconic village consist of calcareous schist and pass gradually into an impure marble.

Farther south, in the neighborhood of Salisbury and Lime Rock, the contact is usually quite sharp or, where a band of schistose marble does lie between the two formations, it is relatively narrow. Only in one place, on the cleared northeastern slope of Frink Hill, are these rocks interbedded.

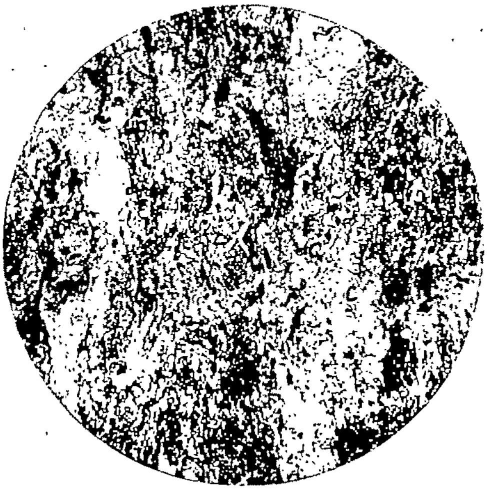


Fig. 2. Calcareous and ferruginous biotite schist from the south side of Tom's Mountain. "C" marks some of the calcite. Plain polarized light, x 15.

Joseph Barrell, in an unpublished manuscript, noted the different characters of the basal schist beds of these two districts. He described the hundred foot thick basal beds in the Miles and Tom's Mountains section as "dark, calcareous and ferruginous beds" which passed up into the other rock; and those in the Salisbury region as coarse garnet, staurolite, feldspar schists. The drift-covered character of the intervening area makes it impossible to trace one type of contact into the other but it appears certain that the schist and the marble are in their normal stratigraphic position[4] throughout this area and, as shown further along, that the schist overlies the limestone.

The Salisbury schist. This schist includes both that composing the ridges east of Salisbury Village and that in the Taconic Range and its southern continuation, Indian Mountain. It includes two strikingly different types of rock which, however, clearly grade one into the other.

From Housatonic River west to the foot of the Taconic Range in Salisbury Village the rock is a coarse biotite-muscovite-garnet-staurolite schist that contains a variable amount of quartz, plagioclase, tourmaline, apatite, titanite, titaniferous magnetite, and fine black dust which is probably graphite. It occasionally contains cyanite. The complex microstructure indicates its complicated metamorphic history. One particularly interesting feature is that a good deal of the staurolite and some of the garnet is crossed by wavy and crumpled lines of black dust-like inclusions. Apparently a phyllite or a fine-grained mica schist with a crinkled foliation formed first. Increasingly intense metamorphism later developed the porphyroblasts of garnet and staurolite and these retained the earlier-formed wavy lines of black dust as inclusions so that a porphyroblastic garnet-staurolite-biotite schist was formed with a helicitic structure in the staurolite and sometimes in the garnet. A later, differently directed pressure resulted in the degradation of the porphyroblastic structure of the rock to a cataclastic structure which is variably developed in different parts. This renewed metamorphism accounts for the present dominant foliation of the schist which shows an incipient retrogression to minerals characteristic of lesser metamorphic intensity. Staurolite is partly altered to chlorite and sericite, biotite to chlorite, and both titanite and ilmenite to leucoxene. The latter is the only alteration that is far advanced. The garnet is unaltered but is fractured and sometimes granulated along the edges.

A number of specimens from the belt of schist along the west and north faces of Barack M'Teth and in the short, isolated ridge in Salmon Creek Valley just southeast of Salisbury, have the old foliation planes greatly crinkled and nearly at right angles to the new foliation. The latter is caused by shearing and drawing out of the ends of the old, partly transposed foliation, and the formation of considerable biotite elongated parallel to the new direction. (Fig. 3.) Another type shows the old micas broken and rotated and new biotite transverse to the old foliation but parallel to the new. This frequently has a helicitic structure. The coarsely porphyroblastic types, which make up the largest part of the schist, do not show such well-oriented new structures. The garnet and staurolite porphyroblasts are sheared, crushed, and rotated so that the helicitic preservations of the old foliation are variably oriented in the rock. These are the schists that have undergone incipient diaphthoresis. Still other types have the old foliation planes completely transposed and exhibit the finely granular, lenticular structure of a phyllonite (Fig. 4). A good deal of new muscovite is developed in many of the rocks. Some of these, as at the top of Mount Prospect, are muscovite, quartz, schists with minor biotite. These could be interpreted as crystalloblastic schists except that the disrupted staurolite, the granulated, lenticular patches of quartz, and the beginning of the chloritization of both the staurolite and the biotite indicate a more complicated history.

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[4] Lime Rock Ridge, where the schist is thrust over the marble, is an exception to this generalization as noted under "structure."

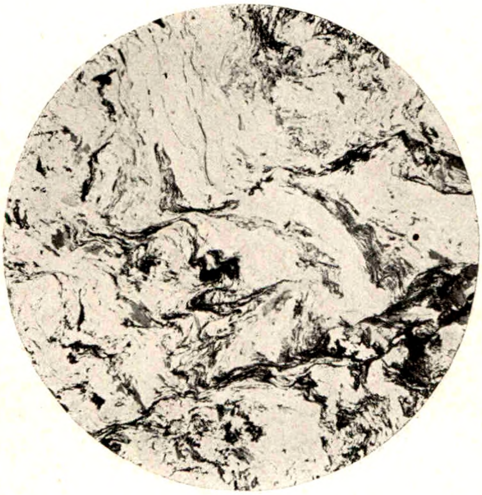

Fig. 3. Salisbury schist from north end of Barack M'Teth. Shows partly transposed foliation planes and development of new direction of cleavage from left to right. Plain polarized light, x 15.

There is nearly every possible gradation between the types described. The composition and texture of the original schist, together with the possibility of varying metamorphic intensity controlled by movement along closely spaced shear planes, has undoubtedly largely determined the present states of the schist. The writer hopes that a further more detailed sampling and microscopic study of the rock will reveal the nature of the control. The problem is complicated, however, by the fact that igneous emanations have penetrated and partly replaced the rock near the close of and immediately after the second period of deformation. Many of the coarse, deformed porphyroblastic types contain a considerable percentage of quartz in lenses or masses made up of strained and sutured individuals larger than the granulated quartz mentioned before. This quartz is accompanied by epigenetic tourmaline and large, unstrained, or very slightly strained, crystals of plagioclase that penetrate the other minerals irregularly and have replaced considerable portions of the finer groundmass of the rock. They retain the helicitic structure of that groundmass as crumpled lines of black dust and small individual crystals that pass completely

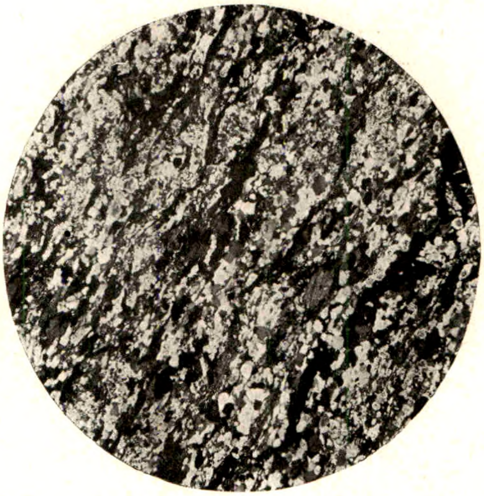

Fig. 4. Salisbury schist from north end of Mount Prospect range. Shows the lenticular structure and the complete transposition of old foliation planes characteristic of a phyllonite. Cross nicols, x 15.

through the large feldspar units and continue unbroken on either side. This is a palimpsest structure superimposed upon the already complicated structure of the schist (Fig. 5). The plagioclase is sometimes oligoclase, sometimes andesine, and occasionally even more calcic.

It is impossible, for the present, to determine how much of the recrystallization which accompanies the latest deformation of the rock is due to the dynamic forces and how much was induced by this granitization which accompanied and partly succeeded the last crumbling. Undoubtedly the introduced material had a considerable effect upon the metamorphism.

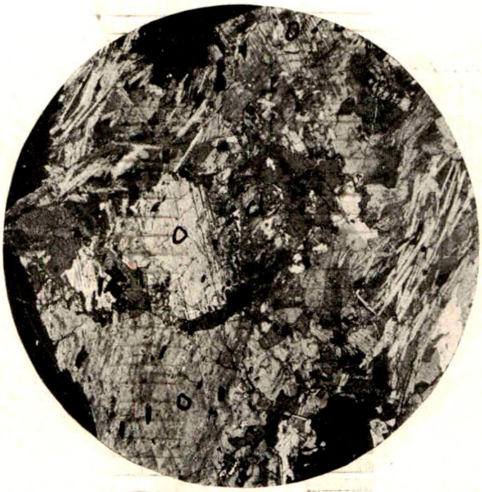

Fig. 5. Salisbury schist from east base of Mount Prospect range near north end. Shows several large crystals of oligoclase (O) with the remnants of an old, crinkled foliation passing through them. Staurolite (S) near center of picture partly altered to chlorite (Cl) and sericite. This is a feldspathized type with a palimpsest structure. Crossed nicols, x 15.

The Salisbury schist of the Taconic Range. The rock on the summit of the Taconic Range is a chlorite-chloritoid-muscovite schist that contains much unequally distributed quartz, some albite, and both graphitic dust and iron oxide. Large garnets and smaller individuals of staurolite are present along the eastern margin of the range. The farther west one goes on the summit of the range the greener and finer grained the schist becomes, and garnet, if visible at all, is rarer and smaller. The microscope shows that these garnets are fractured, granulated, and largely altered to chlorite (Fig. 6). The large garnets along the eastern margin of this belt are also fractured, particularly on their borders, but they are idiomorphic and unaltered. They represent unstable relics. The staurolite of the same belt is much more fractured and shows considerable alteration to chlorite and sericite. Along the eastern slope of the range, above Salisbury, biotite accompanies the minerals described above. At the foot of the range biotite, staurolite, and muscovite take the place of chlorite and chloritoid and the rock grades into that of the eastern belt.

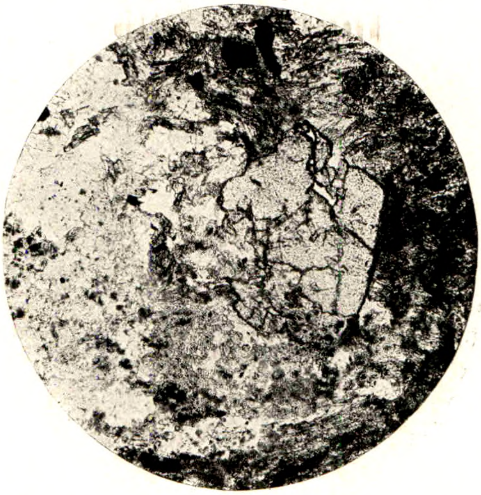

Fig. 6. Salisbury schist from west side of Lake Riga on top of Taconic Range. Shows a garnet crystal fractured and largely surrounded by finely granular garnet and chlorite. The dark border on one side is felted chlorite and the granular material below the large, fractured garnet is also garnet embedded in chlorite. This is an example of diaphthoritic metamorphism. Polarized (plain) light, x 50.

From east to west, therefore, the rock shows a transition from a type characteristic of high or moderate-grade metamorphism to one of low-grade metamorphism, a fact that has long been noted. But it is not a transition due to progressive metamorphism which increased in intensity from west to east. Rather it shows a progressive degradation of a coarse biotite-garnet-staurolite schist in the east to a fine-grained chlorite-chloritoid-muscovite-albite schist in the west. The rock on the crest of the Taconics is a diaphthoritic phyllonite.

Introduced quartz, plagioclase, and tourmaline occur in these rocks also, but the fine-grained phyllitic schist of the western belt shows little or no introduced plagioclase; only rare tourmaline and some quartz.

A palimpsest structure in the schist along the Wochocastinook Brook road south of Lion's Head on the eastern margin of the Taconic Range is shown in Fig. 7. Oligoclase-andesine, itself only slightly strained, has preserved a helicitic structure athwart the present foliation which is developed in the muscovite and chlorite. In this case the plagioclase formed before the new foliation was completed. The rock contains partly altered remnants of staurolite, some garnet, but no biotite.

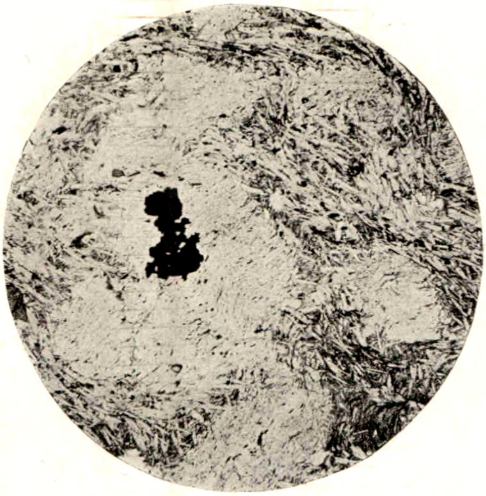

Fig. 7. Salisbury schist from Wochocastinook Brook valley south of Lion's Head. Shows palimpsest structure in oligoclase-andesine which has replaced a part of rock. Plain polarized light, x 15.

The fact that the quantity of the plagioclase introduced during and immediately after the final metamorphism diminishes towards the west suggests that the presence of the magmatic derivatives to a certain extent controlled the temperature at which the last alteration took place. Where a high temperature was maintained by this means the development of minerals typical of low temperatures might be prevented. This is suggested as a part explanation of the divergence between the strike of the foliation and the trend of the western boundary of the zone of high-grade metamorphism. The latter strikes 30° more to the east than the former and passes west of Indian Mountain and north through the eastern flank of the Taconic Range west of Salisbury. It continues about along the same line east of the foot of the range at the northern Connecticut boundary. The degree of feldspathization cannot be the sole explanation for this divergence since the rock at the east base of the Taconic range in Sage's Ravine, at the Connecticut-Massachusetts boundary, is feldspathized but is a chlorite-chloritoid schist with some staurolite partly chloritized and sericitized. On the other hand, Indian Mountain is composed of a medium to fine-grained biotite schist, some parts of which are far advanced towards mylonitization. It contains little or no plagioclase which might be introduced, so its retrogression was not prevented by this means. There is some biotite and staurolite that has been changed to chlorite.

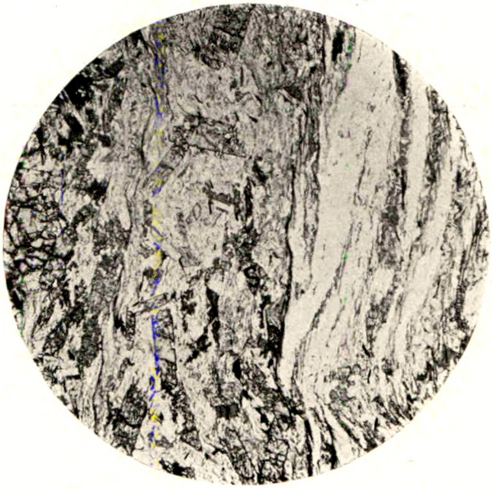

Fig. 8. Salisbury schist from south slope of Taconic Range. Shows lenticles of granular quartz and a foliated mass of muscovite and chlorite with one fractured garnet and large idioblasts of chloritoid and some biotite. There is one staurolite crystal (S) in the center of the picture similar in habit to the chloritoid. A diaphthoritic phyllonite with relic garnet and staurolite. Plain polarized light, x 15.

This divergence in trend has been noted before.[5] The boundary between the two zones probably connects with that in the

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[5] Knopf, E. B., Some Results of Recent Work in the Southern Taconic Area, this Journal, 14, 449-450, 1927.

Turkey Hollow Gorge at Wassaic, which is described in the paper referred to. The explanation of the divergence is not yet at hand. It may be that much of the last metamorphic energy in the region was taken up along a closely spaced series of imbricate overthrusts as suggested in the reference cited. That would explain the erratic recurrence of mylonitized rocks in the region but hardly seems an adequate explanation of the regional diaphthoritic metamorphism.

The generalized history of the Salisbury schist is as follows: A shale of variable composition was metamorphosed into a phyllite or fine-grained mica schist with a crinkled foliation. As the metamorphic intensity increased, porphyroblasts of staurolite and garnet grew in the rock and preserved the traces of the crinkled foliation as fine wavy lines of black dust passing through them. A later pressure from a different direction crushed this schist and developed a new foliation at an angle to the old one. At a late stage in this second metamorphism, and partly after the pressure ceased, granitic emanations entered and partly replaced the rock with the development of a palimpsest structure.

The second metamorphism led to different results in separate parts of the rock but the most marked feature was a regional retrogression from a coarse biotite-staurolite-garnet schist to a chlorite-chloritoid-muscovite schist with relic garnet and staurolite in the Taconic Mountains in the northwest corner of Connecticut. Since this rock has passed through a stage of high-grade metamorphism it cannot be regarded as representing the transition from the highly metamorphosed schists in the east to the very slightly metamorphosed slates of the Hudson valley farther west.

Structure of the region. The area is composed of a series of north-plunging overturned folds of marble and schist bounded on the southeast by an overthrust mass of pre-Cambrian gneisses and scattered unconformable patches of quartzite.

The prevailing structures are synclines overturned towards the west so that steep easterly dips are common. The strike of the foliation varies between N. and N. 20° W. There are two places, however, where broad, rather flat, anticlines lie between the synclinal limbs. Those, together with one syncline, are the localities (noted below) where, on the plunging noses of the folds, the superposition of the schist upon the marble is proved. These are: the synclinal structure of Turnip Top with north-dipping marble beneath it; the northeast part of Miles Mountain at the northeast end of structure section line C-C (Fig. 9); and the northward projecting spur of marble one-half mile south of the summit of Mount Prospect. The broad anticlinal structure in the marble at the base of Sage's Ravine (section A-A, Fig. 9) east of Bear Mountain also shows the superposition of these rocks. The contact between the two formations must undulate in the direction of strike as well, in order to account for the distribution of the schist ridges.

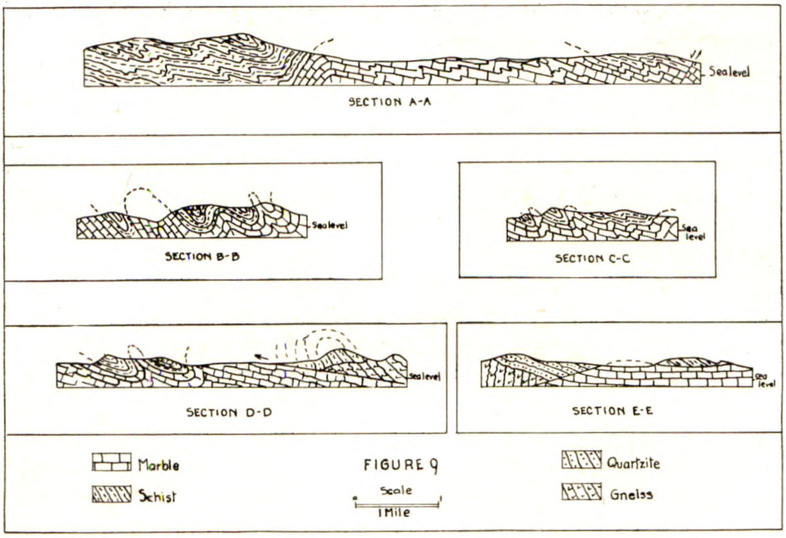

FIGURE 9

The map shows that the ridges of schist west of Housatonic River end abruptly along a line nearly coincident with the present flood plain of the river. The interbedded structures along the east slope of Tom's Mountain and the ridges farther south do not appear east of the river. All the elevations on the east, most of which do not show on the two hundred foot contour map, are marble, usually a greatly silicified variety. This abrupt change in the character of the bed rock is the evidence for the fault indicated on the map. Its continuation south of Mount Prospect is problematic. It is shown on section A-A (Fig. 9) as a normal fault dipping west but its true character is not known.

Section E-E (Fig. 9) shows the gneiss on the south, unconformably overlain by the quartzite, thrust north over the marble, and a continuation of the thrust between the schist and the marble of Lime Rock Ridge. The strikes and dips of the foliation in this ridge are variable and differ considerably in each one of the blocks outlined by faults on the map. They never follow the trend of the ridge. The southwestern end of the schist is faulted against the gneiss and must have been moved northwestward over the limestone with the surrounding gneiss. The writer believes that the whole ridge from Forge Hill, just north of Lime Rock, southwest, is an advance block thrust out beyond the pre-Cambrian gneiss and sliced by a series of northwest-southeast cross faults. The marble of Lime Rock Valley lies beneath the fault block and has been exposed by erosion. Two small, re-entrant valleys floored by marble cut into the ridge from the north near its northeast end.

The evidence for a great overthrust of the gneisses upon the valley rock is scattered. East of South Amenia, N. Y., along the western border of the southerly continuation of the Sharon Mountain upland there is a locality where the gneiss can be seen lying on top of the quartzite and the quartzite on the limestone. The two upper formations dip east. The contact between the marble and the gneiss is not visible anywhere within the area described in this paper but the overturning of the quartzite (Section D-D) and the distribution of the rocks in Lime Rock ridge, as well as their faulted character, indicate a thrust from the southeast.

Section D-D (Fig. 9) shows the two synclines of Forge and Gallows Hills and the marble east of Housatonic River. The last is overridden by an overturned mass of quartzite and gneissoid arkose partly on top of and partly in front of the pre-Cambrian gneiss. The overthrust is here from the southeast at an angle of about forty-five degrees to the section so it is drawn with a very flat dip.

Section B-B (Fig. 9) illustrates the structure in Mount Prospect east of Salisbury. The dips are steep east and the formations are repeated by folding. One-quarter mile south of the section line the limestone passes under the schist along the nose of an anticline which plunges north at a low angle.

CONCLUSIONS.

The Salisbury schist overlies the marble stratigraphically. These formations are folded together into a series of synclines and anticlines overturned towards the west and undulating in the direction of strike. The foliation strikes N 15° W on the average and dips east except in a few localities where, on the nose of a north-plunging fold it dips north, or, on one limb of a fold, it dips west.

The pre-Cambrian gneiss has been thrust northwest and west over the marble.

Housatonic River, within the area here mapped, follows a fault zone. This is mapped as a normal fault which cannot be seen but is necessitated by the juxtaposition of formations.

The Salisbury schist, the best indicator of the metamorphic history of the region, shows a retrogression from a moderate or high intensity metamorphism in the east to a low intensity metamorphism in the west. This schist in the Taconic Range along the New York-Connecticut boundary is not, then, a normal chlorite-chloritoid-muscovite schist which owes its character to lack of more intense metamorphism, but is a diaphthoritic phyllonite. The intensity of metamorphism does not decrease along a line at right angles to the strike of the foliation but along a line that makes an angle of 30° or more to it.

The schist of Canaan Mountain and many other ridges to the south and east of this area is different from the Salisbury schist in many respects. It shows a partial deep-seated retrogressive metamorphism and is believed to represent a separate formation.

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RADIUM IN ROCKS: IV. LOCATION AND ASSOCIATION OF RADIUM IN IGNEOUS ROCKS.

C. S. PIGGOT AND H. E. MERWIN.

In a previous paper[1] brief mention was made of some preliminary experiments that were undertaken with the object of ascertaining which, if any, of the constituent minerals of a granite are most responsible for the radium content: whether the radium is associated with any particular mineral or group of minerals, or whether it is attached indiscriminately to the surface of all the mineral grains. That paper also raised the question of the possible leaching of radium from a granite by water action. In those experiments the constituent minerals were separated by Kline's solution (aqueous solution of cadmium borotungstate) and when the sum of their radium contents was found to be less than that of the rock as a whole, a tentative explanation involved three possible alternatives:

(1) The radium emanation was removed from the surface of the grains by the water of the above solution.
(2) The radium and its corresponding emanation were so removed.
(3) The cadmium borotungstate exercised some specific action on the radium or its emanation.

Such data as were then obtainable indicated that some, at least, of the radioactivity of a granite was removable by boiling water. This paper presents the results of further investigations of these questions.

The experiments involve two granites, one from Stone Mountain, Georgia, and the other from the quarries of the Maine and New Hampshire Granite Company at North Jay, Maine. Both of these rocks have high radium contents; 3.81×10^{-12} and 3.39×10^{-12} grams of radium per gram of rock respectively,[2] whereas the average radium content of the granites in eastern North America thus far reported in the papers referred to is approximately 0.9×10^{-12} grams of radium per gram of rock.[2]

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[1] This Journal, 17, 13-34, 1929.
[2] Radium in rocks: II. This Journal, 21, 28-36, 1931.

These two rocks furthermore have obvious or implied radioactive associations. In parts of the rock mass at Stone Mountain there exist uranophane and other yellow uranium-bearing minerals[3] as thin incrustations on the walls of minute cracks in the rock, and the water from several springs about the base of the mountain is unusually radioactive.[4] However, the samples selected for testing showed no signs whatever of these radium-bearing minerals even when examined with a binocular microscope of high power. The biotite of the rock from North Jay contains a great number of irregularly shaped pleochroic halos.

Each sample was cracked to about the size of the constituent mineral grains and then each was separated into three fractions by means of a powerful magnet.[5] The first fraction contained the non-magnetic quartz and feldspars, while the biotite and muscovite, comprising the magnetic portion, were separated by taking advantage of the difference of their magnetic susceptibilities. Cautious grinding in an agate mortar and separating were continued until each fraction appeared pure on examination with the binocular microscope. By completely separating small samples in this manner the respective fractions of the two rocks were found to be:

TABLE I.

	Stone Mountain	North Jay
Quartz and feldspars	89.9%	91.1%
Muscovite	9.5	5.4
Biotite	0.6	3.5

A microscopic analysis[6] of the North Jay granite (as a check), using four thin sections, gave: muscovite 4.5%; biotite 3.5%. The muscovite was very irregular in distribution, varying from 3% to 6.8%, while the biotite was very uniform.

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[3] Preliminary examinations indicate that one or more of these minerals are as yet not described in the literature, and a report on these uranium minerals at Stone Mountain will be made as soon as possible.

For descriptions of uranophane and its occurrence at Stone Mountain see Packard, R. L., Bull. No. 9-A, Geological Survey of Georgia, p. 115.

[4] Hootman, J. A., this Journal, 21, 37, 1931.

[5] An electromagnetic separator for laboratory use, C. J. Ksanda, Jour. Opt. Soc. Amer. and Rev. Sci. Instr., 13, 713, 1926.

[6] The mode of the Stone Mountain granite is given in the previous paper, Note 2 above.

The experimental data for the radium determinations are given below:

The calibration factor and formula used were:

$$\frac{(E\text{-}F)\times 9428}{W} = \text{grams}\times 10^{-12} \text{ of radium per gram of sample.}^{2}$$

Stone Mountain Granite.

Quartz and feldspars:

No.	Wt. sample in grams	R	N. L.	E.
1	25	0.0063	0.0011	0.0052
2	25	.0059	.0008	.0051
3	25	.0062	.0011	.0051
			Average	0.0051
			Less effect of flux	.0007
			(E-F)	0.0044

Corresponding to 1.65 x 10^{-12} grams of radium per gram of sample.

Muscovite:

No.	Wt. sample in grams	R	N. L.	E
1	5	0.0160	0.0007	0.0153
2	5	.0159	.0006	.0153
3	5	.0160	.0007	.0153
			Average	0.0153
			Less effect of flux	.0007
			(E-F)	0.0146

Corresponding to 27.5 x 10^{-12} grams of radium per gram of sample.

Biotite:

In order to promote ebullition and thereby aid the escape of the emanation from the melt, 5 grams of pure quartz were added to each mixture. The "flux correction" then became 0.0012.

No.	Wt. sample in grams	R	N. L.	E
1	1	0.0031	0.0007	0.0024
2	1	.0034	.0009	.0025
			Average	0.0024
			Less effect of flux	.0012
			(E-F)	0.0012

Corresponding to 11.3 x 10^{-12} grams of radium per gram of sample.

North Jay Granite.

Quartz and feldspars:

No.	Wt. sample in grams	R	N. L.	E
1	25	0.0068	0.0014	0.0054
2	25	.0055	.0005	.0050
3	25	.0053	.0007	.0046
			Average	0.0050
			Less effect of flux	.0007
			(E-F)	0.0043

Corresponding to 1.6 x 10^{-12} grams of radium per gram of sample.

Muscovite.

No.	Wt. sample in grams	R	N. L.	E
1	1	0.0040	0.0006	0.0034
2	1	.0039	.0007	.0032
3	1	.0043	.0007	.0036
			Average	0.0034
			Less effect of flux + quartz	.0012
			(E-F)	0.0022

Corresponding to 20.7 x 10^{-12} grams of radium per gram of sample.

Biotite:

No.	Wt. sample in grams	R	N. L.	E
1	1	0.0040	0.0006	0.0034
2	1	.0043	.0009	.0034
3	1	.0041	.0007	.0034
			Average	0.0034
			Less effect of flux + quartz	.0012
			(E-F)	0.0022

Corresponding to 20.7 x 10^{-12} grams of radium per gram of sample.

In these two granites, each of the micas carries, weight for weight, many times as much radium as do the quartz and feldspars combined; but because of their small concentrations they account for but little more than half of the total radium in the rock (see Table II).

TABLE II.

Mineral association of radium and proportional weights.

Mineral	$g \times 10^{-12}$ Ra per g mineral	% mineral in rock	Proportional radium value of mineral in 1 g of rock	
Quartz and feldspars	1.65	89.9	1.40	Stone Mt. granite determined as a whole: 3.81×10^{-12} g/g
Muscovite	27.5	9.5	2.60	
Biotite	11.3	0.6	0.06	
		Sum	4.06	
Quartz and feldspars	1.6	91.1	1.5	North Jay granite determined as a whole: 3.39×10^{-12} g/g
Muscovite	20.7	5.4	1.1	
Biotite	20.7	3.5	0.7	
		Sum	3.3	

As a result of the above experiments it seems that the radium in mica granites is associated more with the micas than with the other constituents of the rock. Although the explanation of these observations is as yet only a matter for speculation, it is probable that the micas of other rocks will show similar radioactive relationships. The parent radioactive substance may go into solid solution in, or be occluded or adsorbed by, the micas more readily than by quartz and feldspar. Furthermore, segregation from solid solution during cooling may account for the uneven distribution of radioactive materials within some minerals. Another consideration is the fact that the micas often contain halogens, and the halogen salts of uranium and radium are relatively soluble. But in opposition to these ideas is the observed fact that uranophane and the other uranium minerals which have been found in minute concentrations throughout a granite mass are silicates, which are not particularly soluble.

EFFECT OF WATER ACTION.

Preliminary runs[1] on some Stone Mountain fines indicated a difference in radioactivity of 27.8 per cent between the untreated rock and that which had been boiled in distilled water and decanted several times.

In these later experiments the various fractions as well as samples of the rocks as a whole were leached, i.e. boiled in distilled water for five minutes, allowed to settle, decanted, and this procedure repeated twice. The solid was then filtered out and quickly dried in an oven kept at 120° C. The sample was then divided into two equal parts, one of which was set aside, while the radioactivity of the other was immediately determined. After more than thirty days, to permit of the reestablishment of equilibrium between the radium and its emanation, the radioactivity of the other part of the sample was determined in the usual way.

In this manner the results summarized in Table III below were obtained.

TABLE III.

Effect of hot water on the radioactivity of two granites.

Sample	Grams x 10^{-12} of Ra per gram of sample Untreated	Leached	After 30 days	% loss Temporary	Permanent
Stone Mt. Granite	3.8	3.47	3.8	9.	0.
Quartz and Feldspars	1.65	1.5	1.65	9.	0.
Muscovite	27.5	24.7	27.3	10.	0.
Biotite	11.3	10.4	11.3	8.	0.
North Jay Granite	3.4	3.1	3.4	10.	0.
Quartz and Feldspars	1.6	1.5	1.6	9.	0.
Muscovite	20.7	13.7	20.7	34.	0.
Biotite	20.7	20.7 (20.7)	20.7	0.	0.

In these later tests the Stone Mountain material lost only 9 per cent of its radioactivity instead of 28 per cent, as in the preliminary experiments mentioned above. This might be explained by the fact that those first experiments were made on a much finer powder.

It is obvious that this boiling with distilled water removes only the emanation and not any of the original radium. Whether it affects the uranium salts present would not be revealed by these experiments. However, since it is highly probable that the radium would be held within the uranium compound of its origin, the evidence is also strongly against the removal of any uranium. Presumably the uranium which now appears as yellow minerals in some of the fine cracks came originally from the rock mass, but it was moved there by liquids vastly different from distilled water. Presumably there occurred a high concentration of parent radioactive substance on the faces of the mica crystals—the last surfaces to be formed—and it is the emanation from this material only that is removed by the hot water.

It is interesting to note that whereas all the other micas lost some emanation by the leaching process, the biotite of the North Jay rock did not. This was so contrary to the usual experience that the measurement was repeated twice, with independent set-ups, and exactly the same figure (20.7) was obtained in all three experiments. This failure to lose any emanation marks this particular biotite as unique. Presumably the emanation in equilibrium with the radium of this biotite is beyond the reach of the water, and apparently there is none at all on the surface.

The fact that this biotite contains the pleochroic halos may or may not be significant. If the halos are due entirely to thorium held within zircon nuclei, as is generally considered to be the case, the technique of the experiment would preclude any effect on the electroscope—as this technique is adapted to measuring radium only—and the radium which is detected must be somewhere else in the biotite, where its emanation is protected from the water. If the nucleus of the halo contains radium it would appear that none of its emanation has penetrated to the surface, which seems unreasonable.

It would seem that the radium emanation which is removed by the boiling water is merely that which happens to be weakly adsorbed on at easily accessible places. That which is in equilibrium with radium held within a crystal may be protected from the water by the surrounding crystal. However, one would expect even these flakes of biotite to have some easily removable emanation attached to them.

The fact that the percentage of emanation lost by the respective micas is not uniform may be explained on the assumption that this emanation belongs to that radium which is at the surface of the mineral grains in question and not that portion which is held, in whatever manner it may be, deep within the crystal structure. Either that, or else it is emanation from many sources which happens to become adsorbed on the surface of a particular mineral, the quantity being more or less dependent upon the adsorbing condition of the surface in question, and is subsequently crowded off this surface by the more highly adsorbed water.

This explanation does not satisfactorily account for the peculiar behavior of the North Jay biotite, for if it were correct one would expect some emanation, of other origin, to be picked up by it.

This raises the question why a given atom of emanation should become attached to any other mineral once it has left the surface of its origin. As radium emanation (niton) is classed with xenon and the other fixed gases, any tendency to adsorption must be very slight.

SUMMARY.

Two granites of high radium content were separated into their component minerals and these examined in detail for radium.

The radium is associated much more with the micas, weight for weight, than with the other components of the rock. Why this should be so is not evident.

Hot water removes from most powdered specimens some of the emanation in equilibrium with the radium present but apparently does not affect this radium, and probably not the parent uranium. It did not affect the radioactivity of one biotite at all.

The radioactivity of leached samples was completely restored after thirty days.

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THE NORTHERN AREA OF CONNECTICUT VALLEY TRIASSIC.

GEO. W. BAIN.

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SUMMARY AND CONCLUSIONS.

INTRODUCTION.

The northern area of Triassic rocks of the Connecticut valley (Fig. 1) has always been very significant. Hitchcock and Marsh gathered their famous footprint collections here; some of the best fossil fish remains come from it; and now the only known exposures of the eastern contact of the sedimentary fill with the pre-Triassic floor (Fig. 2) have been discovered within its limits.

Location.

The northern area is a remnant of a basin of Triassic sediments which extends north from the Amherst-Northampton highway for about twenty-five miles to Bernardston and Northfield, Massachusetts. The basin may connect with the more extensive one between Northampton and New Haven, Conn.;

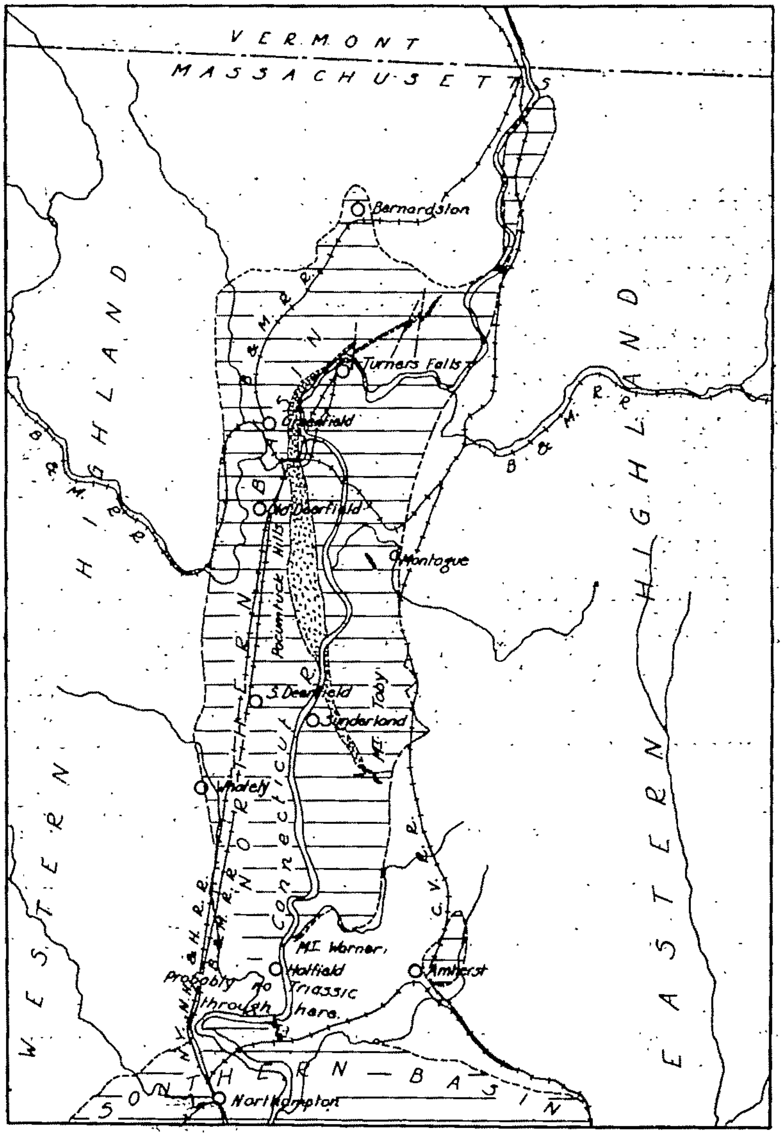

Fig. 1. Map showing distribution of northern area of Connecticut Valley Triassic. (After Emerson with changes at Mt. Warner and Mt. Toby.)

in any event the basins probably joined at one time. The northern area is six miles across in its widest part at South Deerfield.

The College Highway motor road follows the western edge very closely. Rocks of the pre-Triassic complex rise as an escarpment immediately west of the road. The Central Vermont Railroad is close to the eastern edge of the Triassic from Amherst to the north end of the basin; its route follows a series of valleys near the edge of the crystalline complex which crops out along the right of way.

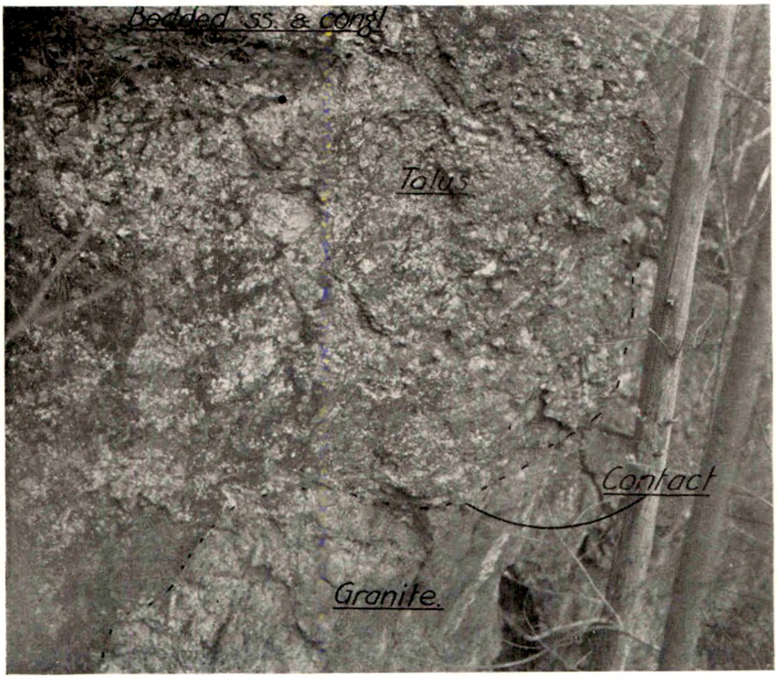

Fig. 2. Photograph of contact of Triassic fill with pre-Triassic complex on east side of Mt. Toby. A talus of angular granite fragments, formed during early Triassic time, lies upon a steeply-inclined granite surface. Bedded sandstone and conglomerate of the Mt. Toby conglomerate overlaps the talus on the west (left side of picture).

General Significance.

Numerous faults have made study of the main areas of Triassic rocks of eastern North America extremely difficult. The northern basin has only one fault cutting the Deerfield trap sheet, which is the lowest and most distinct horizon marker, between the Deerfield River at Greenfield and the south end of the basin. The Triassic rocks are more disturbed near Turners Falls and farther north so that the extreme northern end of the basin is not considered favorable for study of the major valley structure.

High topographic relief on the eastern contact at Mt. Toby (Fig. 3) provides almost continuous exposure where it is most desired. Exposed contacts of the Triassic with the basement complex afford opportunity to study the topography of the pre-Triassic surface and the nature of early deposition in the basin as it is presented nowhere else throughout the length of the Connecticut Valley. Absence of later masking structures and easy accessibility highly commend this area as one in which to study the major basin-making structures of the Connecticut Valley Triassic area.

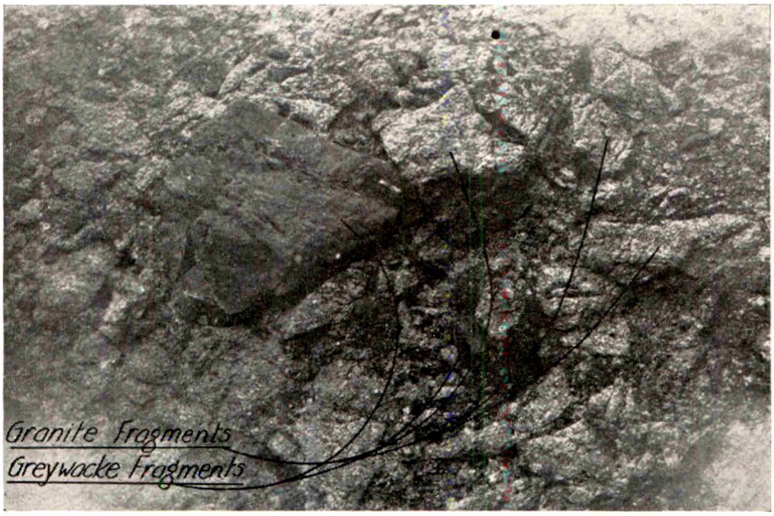

Fig. 2a. Photograph showing detail of the talus deposit. The talus is composed mainly of granite. An occasional greywacke fragment is present. The matrix is arkosic and has a ferruginous cement.

Critical Areas.

Brook beds often furnish critical exposures. The only known exposures of the western contact of the Connecticut Valley Triassic are in or near Roaring Brook, Connecticut;

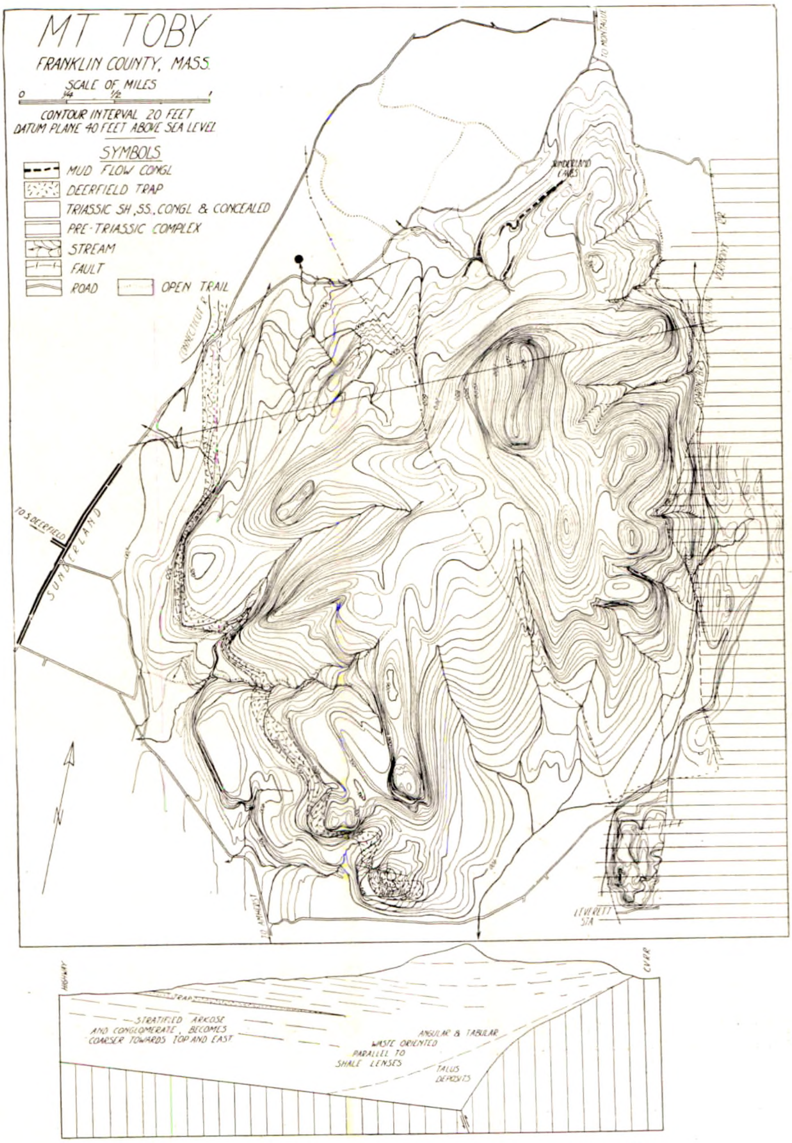

Fig. 3. Geologic and topographic map of Mt. Toby.

the only known exposures of the eastern contact are near and on either side of Roaring Brook, Massachusetts. (See Fig. 3.) Extended exposures of the contact and of the pre-Triassic complex occur just south of the brook. (Fig. 4.)

An excellent cross section of the older rocks of the fill occurs on Bull Hill. (See Fig. 3.) Weaknesses in the Deerfield trap, due to primary shear, have been accentuated by weathering; they indicate flow of the trap from west to east to bring it as an overlap on the fans and conoplain* being built out from the spurs projecting from the eastern highland. North of Sunderland the flow has numerous cylinders of

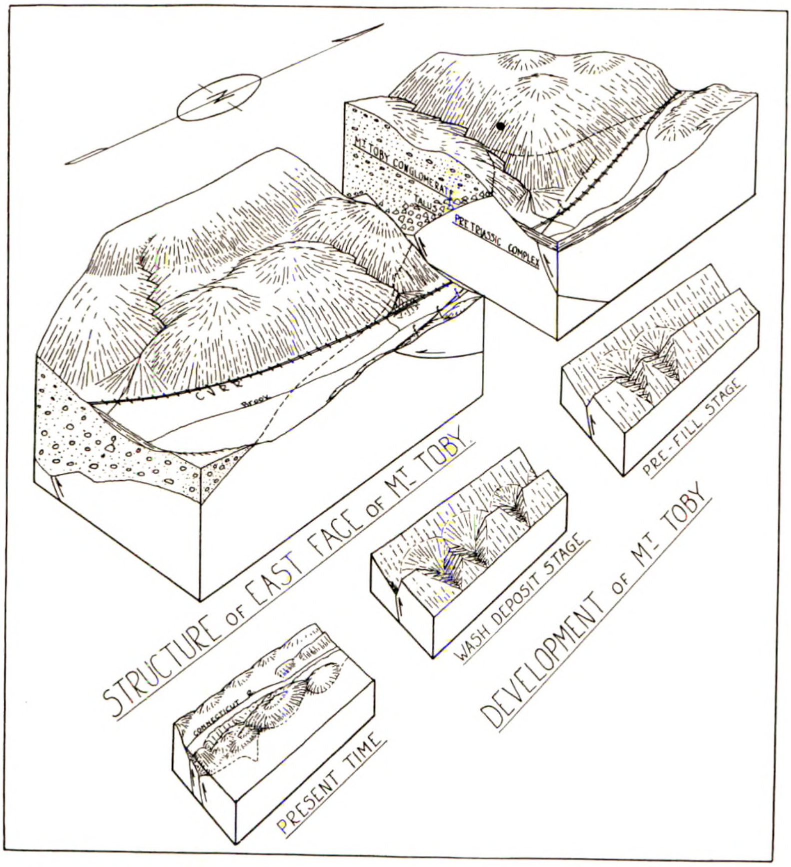

Fig. 4. Block diagram showing structure of north end of Mt. Toby and development of the mountain group.

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* Conoplain as used here signifies a gently inclined surface of aggradation produced by convergence and overlapping of a series of nearly flat alluvial cones and fans.

bubble holes formed by escape of gas when the lava was nearly solid. The bubbles curve forward in the center of the flow and indicate motion northeastward from conduits which lay southwest of Sunderland.

Fanglomerates with boulders up to six feet in diameter overlie the eastern edge of the trap on Bull Hill. Soled pebbles, especially striated ones, occur in the fanglomerates and suggest rapid transport from regions of alpine glaciers.

Shaly greywacke lake deposits near Sunderland Caves (see Fig. 3) contain fossil fish and plant fragments. Three series of lake beds are highly disturbed and contorted in the vicinity of unassorted masses of angular rock fragments. The disturbed structures indicate a salient of an alpine glacier lobe, of a landslide, or of a mud flow; in any case they identify a steep mountain range immediately east of the region of the lake deposits.

Bearing Upon the Connecticut Valley Problem.

The Connecticut Valley problem is the determination of the origin or principal origin of the basin now filled by sediments of Triassic age. Barrell[1] pictured the southern basin as bounded on the east by a normal fault, on which movement began after sedimentation started. Emerson[2] dissented from this view in believing that a graben existed before sedimentation and that later fault movements were secondary features which merely accentuated the basin in some instances and masked the real structure in others. It seems possible, and even probable, that features of minor importance in the northern basin may be responsible for the larger size of the southern one and become of major importance in it. However, the critical parts of the northern area occur where masking and complicating secondary structures are absent, and these parts seem to hold structural, sedimentational and paleophysiographic evidence of the first order of importance bearing on the problem. This additional information on the northern area may be helpful in completing the study of the more complex southern one. The significant features fall into three groups which are:

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[1] Barrell, J., Central Conn. in the Geologic Past., Conn. Geol. and Nat. Hist. Sur. Bull. 23.

[2] Emerson, B. K., Geol. of Mass. and R. I., U. S. G. S. Bull. 597, pp. 90-91.

1. Triassic structure.
    - a. Absence of faults of later age than the sediments.
    - b. Sediments on the west side of the valley have finer texture than those of corresponding age on the east.
    - c. Sediments on the west side of the valley dip east; sediments on the east side of the valley lie horizontal or dip slightly west.
2. Pre-Triassic structure.
    - a. Presence of steep angle thrusts of earlier age than the sediments.
    - b. Absence of faults having the appearance of normal types.
3. Topography of the Triassic floor.
    - a. Exposures of the Triassic floor show rugged topography.
    - b. Piedmont type of sediments on the Triassic floor.
    - c. Thinning of the trap sheet eastward.
    - d. Fanglomerates with boulder texture above the eastern edge of the trap.
    - e. Lake deposits disturbed by landslides or mud flows of moderately distant origin.
    - f. Features in the lava indicating the direction of its source.

Each of the above lines of evidence will be considered in detail and critical localities described to substantiate conclusions on each.

GENERAL GEOLOGY.

The northern and southern areas contrast strongly in their stratigraphy. Four sandstones, three trap sheets, and one tuff bed occur in the southern area. Only two sandstones and one trap sheet can be distinguished in all parts of the northern area. The lowest trap sheet of the southern region does not come north of the Westfield River and the sandstones older and younger than it are indistinguishable in its absence. The Holyoke trap is a compound sheet poured out as a series of flows on the sandstone and conglomerate. This lava flowed N. 50° W. near the middle of the Holyoke Range. Conglomerate covers the Holyoke trap and is in turn overlain by a flow of lava. This flow is discontinuous along the Holyoke Range but becomes thick and regular along Mt. Tom. Tuff lies above it as far south as Holyoke. Fine red sandstone rests on tuff, where present, and elsewhere upon the upper trap.

The northern basin has a lower conglomerate and sandstone with a thick trap, the Deerfield sheet, poured out upon it. The thickness and regularity of this sheet, and occurrence of footprint beds at Turners Falls about as far above this lava as similar beds lie above the Holyoke sheet of the southern area, suggest that the Deerfield sheet of the northern basin corresponds to the Holyoke sheet of the southern one.

The two areas differ in complexity of structure. Trap sheets and even the third sandstone of the southern area are faulted at close intervals. The northern area has been studied in very great detail and the trap traced from Bull Hill to east of Old Deerfield; the contact with the sediments above and below is faulted at Bull Hill only and the break is transverse to the length of the basin. Absence of modifying and masking structures in the northern basin leave the major features prominent by contrast with those of the southern area.

STRATIGRAPHY.

Stratigraphy of the northern area is best considered as a thick clastic series of rapidly-accumulated sandstone and conglomerate. One very brief period of vulcanism produced a lava flow which divides the sediments into two groups and serves as a convenient horizon marker. The formations and their correlation with the southern basin are given in the following table.

TABLE OF FORMATIONS.

Connecticut	*Southern Mass.*	*Northern Mass.*
Upper shale, sandstone and conglomerate	Chicopee shale, Longmeadow sandstone, Third sandstone	Lake beds, Mt. Toby conglomerate and sandstone
Posterior trap	Granby tuff, Second trap	Sandstone and conglomerate
Posterior shales	Second sandstone	Conglomerate and sandstone
Main trap sheet	Holoyke sheet	Deerfield sheet
Anterior shales, Anterior trap sheet, Lower sandstone, arkose and conglomerate.	First sandstone and conglomerate	Sugarloaf arkose

Sugarloaf Arkose.

The Sugarloaf arkose is exposed northward from Mt. Sugarloaf at South Deerfield along the Pocumtuck Hills and at a few localities in Whately, Greenfield and Sunderland. The rock is made of little worn and weathered quartz, feldspar and mica fragments. Pebbles over two inches in diameter are unknown on the extreme western side of the basin at Whately and Bernardston and make up less than five per cent of the sediments in the Pocumtuck Hills and Mt. Sugarloaf. This suggests coarser texture towards the east but is not conclusive because the Whately and Bernardston exposures are stratigraphically far below those on the Pocumtuck Hills.

Pebbles become the dominant constituent east of the Connecticut River; boulders up to a foot in diameter are not uncommon in the arkosic conglomerate on Bull Hill. This horizon lies below the trap sheet and corresponds stratigraphically to the arkose in the Pocumtuck Hills. Increase in coarseness of texture eastward is therefore an actual pronounced and distinctive characteristic of the Sugarloaf arkose.

Deerfield Trap.

The Deerfield trap outcrops from Bull Hill to a short distance northeast of Turners Falls. The sheet, which consists of fine-textured diabase, is generally less than 100 feet thick; it thins eastward and pinches out at the southeast end of Bull Hill, whereas the thickest part is along the east slope of the Pocumtuck Hills from Sunderland to Greenfield. Two parts of the trap are significant enough to merit detailed descriptions; they are the exposures at the southeast corner of Bull Hill and that part of the sheet along the Connecticut River above Sunderland.

Trap near the top of Bull Hill is overlain by approximately thirty feet of conglomerate and sandstone. The upper part of the flow is extremely vesicular and this structure extends from top to bottom at the most easterly outcrop where the lava is only ten feet thick. Shear joints, produced by flowage in the viscous mass, incline upward towards the top and eastern edge of the flow; they are exceedingly abundant in the sheet near its eastern limit and also in the more massive diabase adjoining.

The flow is approximately 100 feet thick north of Sunderland where it crosses from the east to the west bank of the Connecticut River. Exposures parallel to the original lava surface are dotted with circular areas of bubble holes about one inch in diameter. These are very common throughout the Deerfield sheet, but especially in a quarry about one mile north of Sunderland. Cylinders of bubble holes in this quarry are not straight, although they are almost normal to the base of the sheet; they show accelerated deflection towards the northeast towards their top. The accelerated deflection is believed to be due to flow of the central and upper part of the trap after the bubbles had formed and while the rock was still viscous. Flow would be in the direction of accelerated deflection, that is from southwest to northeast, and the volcanic vents would be located somewhere southwest of the trap quarry.

Mt. Toby Conglomerate.

The Mt. Toby conglomerate may be divided into two parts. This arbitrary division depends, however, upon the fact that the lower member is not found east of Bull Hill, and an eastward extension from the outcrop of this part of the deposit is not exposed at any place farther north.

Fifteen feet of fine, thin-bedded, red sandstone lies above the trap at Bull Hill. Deposits of this texture and structure have interstratified conglomerates and thicken to over five hundred feet as they are followed northwest along the outcrop to east of Turners Falls. Footprints of bipedal dinosaurs and small quadrupedal dinosaurs are found in the upper half of these fine-textured red sandstones. Tracks of exceptionally large dinosaurs are not known in this locality and are rare even at South Hadley and Holyoke, but every small species reported from the last named localities have been found at Turners Falls. The upper part of the fine-textured sandstone above the trap is, therefore, correlated with formations between the Holyoke sheet and the footprint bed of the southern basin.

Conglomerate overlies the sandy phase resting upon the trap. Pebbles are rarely as large as four inches in diameter in deposits outcroping more than one mile west of the eastern border of the Triassic sediments. Sizes increase as the deposits are followed eastward, especially around the south end of Mt. Toby. Many boulders are five to six feet in diameter in the coarsest deposits at about 300 feet above the trap. This extremely coarse boulder deposit is poorly stratified, and approximately 250 feet thick; towards the top it becomes a normal conglomerate with an arkosic matrix.

The boulder formation is buried through the central part of the mountain by younger Triassic sediments. Slightly worn tabular and angular fragments in poorly stratified deposits predominate in the lower beds at the extreme north end of the mountain. They have been described as outwash from a highland by Emerson and called screes by Reynolds.[8] The fact that the underlying rock and observed talus deposits are granite, the fact that these deposits of tabular fragments not only have most pieces laid parallel and flat but also have shale lenses parallel to the slabs laid in parallel orientation, and the fact that the slabs have their corners rounded and projections worn off, are evidence indicating water transport through some part of their travel before deposition. These deposits are more properly spoken of as wash accumulations rather than slide rock or screes. Conglomerates similar to the upper ones at the south end of Mt. Toby overlie the wash deposits.

Occasional gray, red and black shales regarded as lake beds occur in the conglomerate. Less commonly an unstratified deposit of angular boulders varying in size from dust particles to ten feet in diameter, is associated with the lake beds; these boulder deposits are believed to be Triassic landslide deposits or mud flows.

The lake beds. Carbonized plant fragments give thinly laminated shale a black color. Deposits with less plant material are gray colored shaly greywackes. Red shales with occasional interstratified gray beds are less frequent. Impressions and casts of crystals occur locally; Emerson believed these were salt crystals but Abel who has examied them more recently, is of the opinion that they bear greater resemblances to frost crystals around desert playas. Fossil fishes are abundant in some of the lake beds; although individuals are numerous only three or four species are represented, a suggestion of rigorous living conditions. The best specimens come from the east bank of the Connecticut at Whittemore's Ferry. Specimens have been found at other localities and one complete skeleton was taken from the shale beds at Sunderland Caves.

The mud flows or landslide deposits. Boulder deposits rest on lake beds at three stratigraphic levels at the north end of Mt. Toby. The boulders are extremely angular, unassorted in size and composed mainly of very fine-textured actinolitized argillite resembling fragments composing so large a part of the wash deposits.

Boulder deposits at each of three horizons pinch out completely along parts of their outcrop and increase to thirty feet in thickness at others. Lake bed clays below them are pushed laterally (Fig. 5) and minor folds are overturned away from the boulder accumulations. The lake beds can be followed for over a quarter of a mile away from the disturbed area and show no evidence of erosion; the record is one of continuous deposition. This is very strong evidence against the interpretation that the boulder deposits are remnants of a continuous bed which here and there sank into the lake muds and was preserved, while, where the base on which it was deposited was firm, it did not sink and was eroded away. The laterally shoved lake clays favor the interpretation that the exposures are a cross-section of a large deposit of angular boulders with a lobate

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[8] Reynolds, D. D., and Leavitt, D. H., A scree of Triassic Age, this Journal, 13, pp. 161-171.

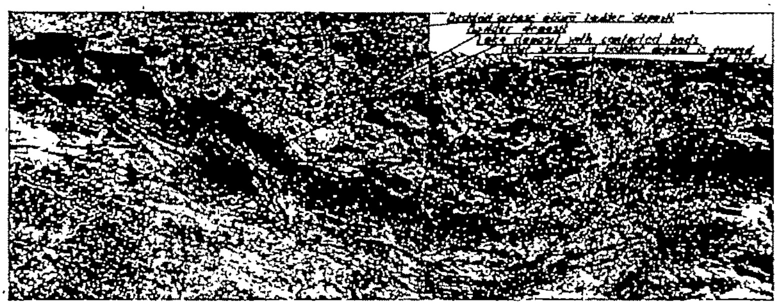


Fig. 5. Photograph showing the mud flow or landslide deposit at Sunderland Caves. North to left, south to right. The boulder deposit is about eight feet thick at this place. Farther south it becomes much thicker. Note the crumpled bedding of the shale below and the horizontal attitude of the arkosic sandstone and conglomerate above. The under surface of the deposit is grooved and fluted in an east-west direction and indicates movement from the east.

front. A fluted contact between the boulder deposit and the lake clays indicates that the boulder mass moved into place as a unit of only moderate mobility and possessing considerable rigidity. Such conditions might be produced along the front of a piedmont glacier, a landslide, or a mud flow.

Varved clays or varved deposits of any type are lacking in the lake beds or immediately adjoining deposits. Only two boulders having a definite glacial origin have been found in the Triassic sediments of this region and they came from beds stratigraphically below the boulder horizons. Abrupt variations in thickness of deposit, excessive lateral thrusting of the lake beds and a fluted contact surface between the boulder deposit and the lake beds suggests a landslide accumulation rather than a mud flow. On the other hand, predominance of angular material under two inches through, and the scattered distribution of five and ten foot boulders give the accumulation some distinctive properties of a mud flow. The contemporary stage of topographic development of the mountain range to the east, of which a description follows, favors the mud flow interpretation. Mud flow or landslide, the deposit points clearly [illegible] a mountain range with steep front whence the boulder ma[illegible] moved into the Sunderland Caves region.

The boulders are largely actinolitized argillite with no perceptible granitization. The root of the mountain range from which the boulder deposits were derived is composed of granite and occasional pendants of granitized rocks. Studies of granitization along the Deerfield River valley show very little difference in intensity of change in the thousand foot vertical range of the valley walls. The expectability therefore is that the nongranitized rocks of the boulder deposits came from a great height above the granite basement and consequently from a great height above their present resting place. The mountain range, therefore, had a steep front and was at least moderately high.

The same thin arkose bed lies across the top of the boulder deposits showing that they were smoothed out or worn essentially level with their surroundings before the overlying rocks were laid on them.

STRUCTURE.

A general picture of the northern Triassic area shows an eastward dipping series of arkosic and conglomeratic sediments with a single lava flow not far from the middle of the series. The dip of the beds suggests a fault termination on the east, the faulting having occurred contemporaneously with deposition or at a later date. Detailed study, however, has added so many corrections to the general picture that it cannot be recognized in the final one to be presented. The final picture can be developed most clearly and easily along three independent lines as follows:

1. Structure of the Triassic rocks.
2. Structure of the pre-Triassic rocks.
3. Topography of the Triassic floor.

TRIASSIC STRUCTURE.

The Triassic arkose, conglomerate and trap in the west half of the valley have a remarkably uniform eastward dip of approximately 8°. Beds become horizontal just east and also north of the Sunderland Caves. Bedding of shale lenses in the conglomerate along the eastern edge of the Triassic belt dips 4° to 8° west. These convergent dips in extremely fine-textured shales, which must have been deposited in essentially horizontal position, indicate a synclinal structure in the uppermost beds.

The Deerfield sheet is a very distinctive horizon marker and can be traced, with only one break, from the south end of Bull Hill to the Deerfield River at Greenfield. The single break in continuity occurs in the middle of Bull Hill; rocks north of a fault striking N. 67° E. and dipping 70° northward have been dropped about 120 feet. Thus strike of the only fault plane cutting Triassic rocks between Amherst and Greenfield is transverse to the strike of the rocks. Eastward dip of the beds, therefore, is in no wise due to faulting unless it is immediately adjacent to the eastern border of the Triassic belt.

Contact of the Triassic with the pre-Triassic floor is well exposed along the east side of Mt. Toby. The sediments rest with depositional contact upon gneiss, schist and granite. Exposures are continuous enough to show that faults either at the contact or at any point in the Triassic rocks west of it are completely lacking. Structure of the Triassic of the basin is therefore in no wise due to faulting in or along the edge of the basin after extrusion of the Deerfield sheet.

PRE-TRIASSIC STRUCTURE.

Slate, argillites and andesitic volcanics, along with extensive granite masses breaking up into them and metamorphosing them to schists and gneisses, comprise the great bulk of rocks of the pre-Triassic complex. Faults, approximately parallel to the length of the valley, cut the complex at many places along its eastern border and at an occasional place west of the Triassic basin. Some fault zones are filled and cemented by barite, galena, sphalerite, chalcopyrite and quartz; others by quartz only; still others have well-formed barite or quartz crystals on the walls of vugs; and a few have a small amount of carbonate filling between fragments.

Granite and schist along any fault plane is intensely distorted. Intermittent torsion cracks and crush zones extend more than 100 feet from faults on the east face of Mt. Toby, and the zone of distorted granite on the east side of the Leverett lead vein is over 100 yards wide. Slickensiding on the granite walls of the vein indicates that the last movement was nearly horizontal, the east wall moving up and north at about 10°. Slickensiding on another fault plane on the east side of Mt. Toby shows a final movement of the east wall upward and south at about 40° to the horizontal.

The fault planes dip eastward, or away from the basin, at angles ranging from 40° to nearly 90°. Granite, lying east of a large curtain of schist, is thrust westward and upward upon the schist along a fault plane exposed south of Roaring Brook. This fault is one of the general series found in the crystalline rocks through a belt extending for one-half mile east of the Triassic. The following evidence, which is all that is available, indicates that the major faults, adjacent to the east side of the basin, are high angle thrusts.

1. Granite overthrust upon schist west of it along a plane inclined steeply to the east.
2. A few fault planes are practically vertical but most dip eastward or away from the basin.
3. The extensive development of torsion and shear structures throughout the broad zone bordering on the Triassic basin indicates thrust forces. Rare occurence of breccias along fault planes indicates thrusts rather than tension types.

Since the edge of the basin is buried in wash from the Eastern highland, conclusive proof of the type of fault making the basin is lacking at the present time even although the evidence strongly favors the thrust type. It is the author's opinion that a high angle thrust or series of thrusts formed the basin and the highland east of it.

TOPOGRAPHY OF THE TRIASSIC FLOOR.

Topography of the Triassic floor can be viewed in profile on the east side of Mt. Toby. Elsewhere the form of the basement can be pictured only from effects it has produced upon rocks which are visible. Such effects include:

1. Regularity or irregularity of contact of the pre-Triassic complex with the Triassic fill.

2. Texture and primary structure of sediments washed into the Triassic basin by streams moving over the Triassic floor.

Each of the above lines of evidence furnish very suggestive information which serves to fill out that obtained from direct observation along the eastern contact.

Contact of pre-Triassic complex with Triassic fill.

The boundary between the pre-Triassic crystalline complex and the Triassic fill is extremely irregular and the linear boundary shown on earlier maps is far from fact. This contact follows approximately the line and level of the Central Vermont Railroad. However, at two places the contact rises more than 250 feet above the track level and extends about one-quarter of a mile west from it. About one-half mile north of Leverett station, the Triassic reaches into the Eastern highland for more than one-quarter of a mile. Rise of the crystallines above their

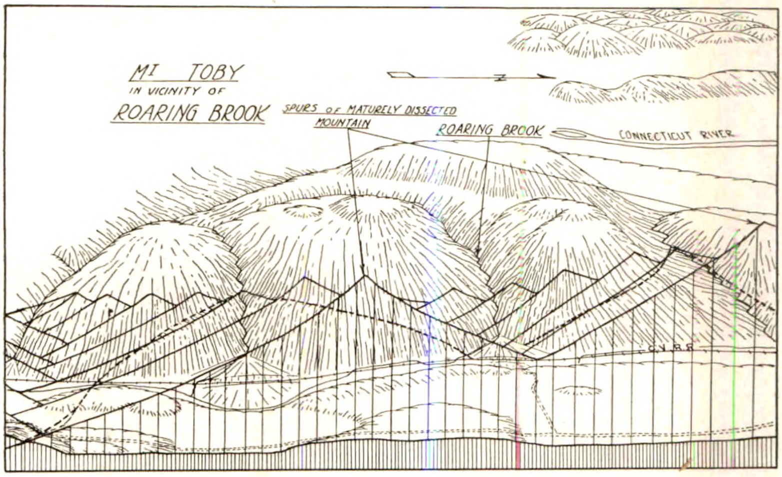


Fig. 6. Sketch showing position of spurs of buried pre-Triassic mountain relative to present topography of east face of Mt. Toby. The spurs slope steeply westward. The valleys between them are filled with wash deposits, their sides have a thin deposit of talus and their crests are buried with rounded pebbles and arkosic sand.

average level and extension westward beyond their average boundary occurs on long serrate spurs buried in Triassic deposits (Fig. 6). Extensions of Triassic sediments into the area of crystallines are seen to be valleys filled with waste from the highland. Consequently when, as at present, the serrate spurs are planed off flat, the boundary of the crystallines with the conglomerates represents the position of a contour line on a former dissected mountain front.

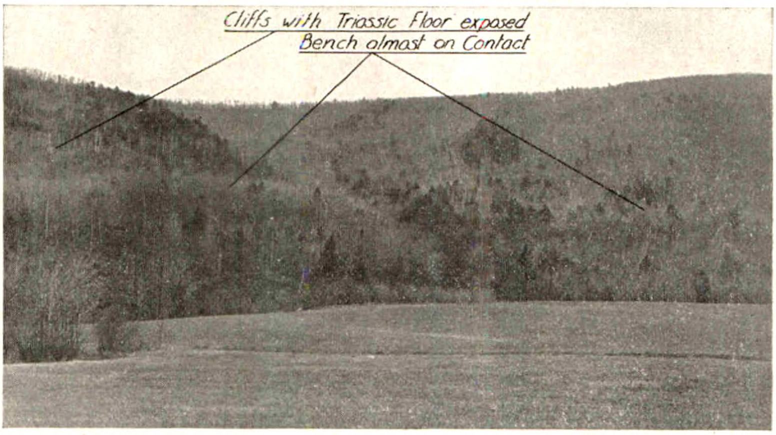


Fig. 7. Photograph of east face of Mt. Toby where one of spurs of the pre-Triassic mountain passes beneath the Triassic fill. Intersection of the spur with the present hillside corresponds to the bench in the middle of the photograph. This bench slopes down from the center of the photograph to ground level a short distance beyond the limits of the view.

The contact between the granite of the pre-Triassic complex and the Mt. Toby conglomerate is well exposed at numerous places along the westward-pitching spur south of Roaring Brook. The crest of this spur corresponds closely to the first brook south of Roaring Brook (Fig. 7). An arkosic conglomerate of rounded pebbles lies upon the granite on the crest of the spur. The southern side of the spur slopes southwest at approximately 20°, and the Triassic deposits upon it are angular unassorted granite blocks exactly similar to the rock upon which they rest. Position of the fragments, material from which they are made and structure of the deposit are associated features which could occur only in a talus deposit.

Steeply-pitching triangular spurs, such as these, are characteristic of fault scarps in a mature stage of dissection. The steep slopes and talus deposits also indicate an early mature stage of erosion. Rounding of the pebbles in the conglomerate upon the top of the spur indicates high degree of mechanical wear of the fragments, in contrast to the slight degree represented by the extreme angularity in lower beds. High degree of wear suggests a late mature stage of erosion and reduction of the scarp by the time the spurs became buried to the extent seen on the east side of Mt. Toby.

Contact of the main Triassic area and the crystallines is not exposed north of Mt. Toby. An outlying ridge of crystalline rock almost completely surrounded by wash deposits is exposed one mile west of Montague. The ridge, which is made of granite gneiss, strikes N. 15° W. and is exposed intermittently for about 4,000 feet, but does not join the main area of crystallines. Talus on the flanks of this ridge is seen lying on the steep granite slopes about 500 feet southwest of the first three corners west of Montague. The talus is never over 20 feet thick. Wash accumulations surround the ridge and associated talus deposits on all sides.

Texture and structure of sediments washed into basin.

The sediments of the northern basin resemble deposits on a westward facing piedmont slope. Decrease in coarseness of deposits from east to west has been indicated already. Features which reflect the topography of the eastern highland are given in the following sections.

The wash deposits. Deposits of stratified tabular fragments are the most common types in the Triassic fill for about one-half mile westward from the edge of the crystallines. Accumulations of slide rock, which they cover, are thin and limited to within twenty or thirty feet of the ridges of crystallines. The wash deposits of tabular and semi-angular fragments occur between the points of truncated spurs of crystallines projecting into the Triassic area; rounded pebbles are characteristic of deposits on top of spurs in the vicinity of Roaring Brook. The shape and type of stratification in the lower deposits along the eastern edge of the valley indicate flood wash as the agent of transportation to their present position.

Wash deposits indicate high, abrupt topography at their source; they are composed largely of metamorphosed greywacke and argillite showing negligible amount of granite injection. The fragments are laid on granite and highly injected gneiss. Extensive erosion of the mountain block must have preceded deposition of this part of the fill in order that the granite beneath might be exposed to be covered over by waste coming from farther back in the highland.

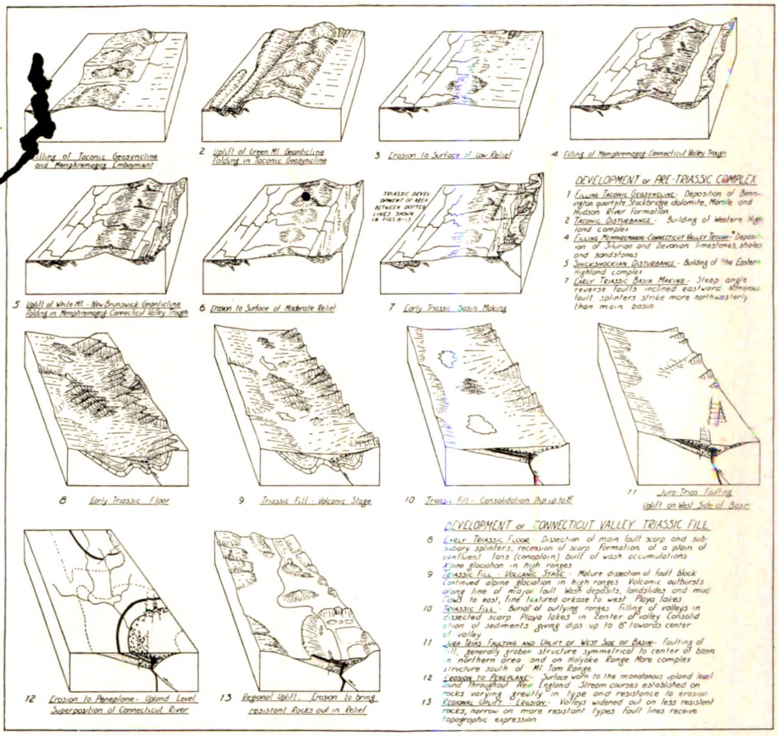
Degree of topographic relief.

The characteristics of sediments along the east side of the valley may be summed up as follows:

1. Talus deposits adjacent to the sloping parts of the basin floor.
2. Wash deposits of slightly worn tabular fragments of moderately distant origin in valleys between spurs and in reëntrants to the highland.
3. Poorly stratified conglomerates with rounded boulders up to six feet in diameter covering the spurs and wash deposits.
4. Mud flows or landslides with boulders of non-granitized argillite up to ten feet through occurring over a mile from the foot of the mountain.
5. Faceted and striated pebbles (glacially shaped) in stratified boulder deposits.

The aggregate evidence overwhelmingly favors a steep mountain background with fairly well-developed valleys to control flood discharge and transport exceedingly coarse material. Boulders in the mud flow or landslide deposits came from far enough above the granite masses to be above their metamorphic zone. Furthermore, the hinterland seems to have been high enough to have a few glaciers which shaped many of the pebbles in the conglomerates; striations on most of these glacially shaped pebbles have been removed by later water transportation.

The irregular boundary of the Triassic fill is not a fault contact. It resembles a dissected mountain front with outliers buried in their own waste and to-day planed off to show their outline at their present contour of elevation. Exposed contacts show steep mountain sides and spurs pitching westward. Certainly the mountain mass had reached a mature stage of dissection by the end of the Triassic if not by the middle of the period of deposition. Its development is illustrated in Figure 8.


[illegible] illing of Taconic Geosyncline and Memphremagog Embayment
2 Uplift of Green Mt Geanticline Folding in Taconic Geosyncline
3 Erosion to Surface of Low Relief
4 Filling of Memphremagog-Connecticut Valley Trough
5 Uplift of White Mt - New Brunswick Geanticline Folding in Memphremagog Connecticut Valley Trough
6 Erosion to Surface of Moderate Relief
TRIASSIC DEVELOPMENT OF AREA BETWEEN DOTTED LINES SHOWN IN FIGS. 8-13
7 Early Triassic Basin Making
8 Early Triassic Floor
9 Triassic Fill - Volcanic Stage
10 Triassic Fill - Consolidation Dip up to 8°
11 Jura-Trias Faulting Uplift on West Side of Basin
12 Erosion to Peneplane - Upland Level Superposition of Connecticut River
13 Regional Uplift. Erosion to bring resistant Rocks out in Relief

DEVELOPMENT OF PRE-TRIASSIC COMPLEX

1 Filling Taconic Geosyncline - Deposition of Bennington quartzite, Stockbridge dolomite, Marble and Hudson River Formation
2 Taconic Disturbance - Building of Western Highland complex
4 Filling Memphremagog-Connecticut Valley Trough - Deposition of Silurian and Devonian limestones, shales and sandstones
5 Shickshockian Disturbance - Building of the Eastern Highland complex
7 Early Triassic Basin Making - Steep angle reverse faults inclined eastward. Numerous fault splinters strike more northwesterly than main basin

DEVELOPMENT OF CONNECTICUT VALLEY TRIASSIC FILL

8 Early Triassic Floor - Dissection of main fault scarp and subsidiary splinters; recession of scarp. Formation of a plain of confluent fans (conoplain) built of wash accumulations. Alpine glaciation in high ranges
9 Triassic Fill - Volcanic Stage - Mature dissection of fault block. Continued alpine glaciation in high ranges. Volcanic outbursts along line of major fault. Wash deposits, landslides and mud flows to east, fine textured orkose to west. Playa lakes
10 Triassic Fill - Burial of outlying ranges. Filling of valleys in dissected scarp. Playa lakes in center of valley. Consolidation of sediments giving dips up to 8° towards center of valley
11 Jura-Trias Faulting and Uplift of West Side of Basin - Faulting of fill, generally graben structure symmetrical to center of basin in northern area and on Holyoke Range. More complex structure south of Mt Tom Range
12 Erosion to Peneplane - Surface worn to the monotonous upland level found throughout New England. Stream courses established on rocks varying greatly in type and resistance to erosion
13 Regional Uplift - Erosion - Valleys widened out on less resistant rocks, narrow on more resistant types. Fault lines receive topographic expression

Fig. 8. Block diagrams showing development of Connecticut Valley and adjacent highlands in Massachusetts, Vermont and New Hampshire.

SUMMARY AND CONCLUSIONS.

1. The eastern contact of the Triassic sediments of the northern area with the crystalline complex is not straight as usually shown on maps but is extremely serrate.
2. The eastern contact between Bull Hill and Montague is a deposition contact with no evidence of faulting later than deposition.
3. Deposition occurred in a basin at the foot of a steep mountain block, in a mature stage of dissection, possessing steep spurs and outlying ridges.
4. Available evidence indicates that the mountain block was made by steep angle thrust faulting from east to west. Faulting was distributed over a wide crush zone of minor faults at a slight angle to the general trend of the basin.

AMHERST, MASS.

A NEW PALLASITE METEORITE FROM NEWPORT, ARKANSAS.

H. H. NININGER.

The state of Arkansas has claimed a large share of attention from students of meteorites during the year 1930.

On February 17, 1930, occurred the fall near Paragould which gave us the largest individual stony meteorite yet collected and the largest meteorite ever recovered intact from any witnessed fall. This fall also yielded two other masses, one of which weighed about 85 lbs.

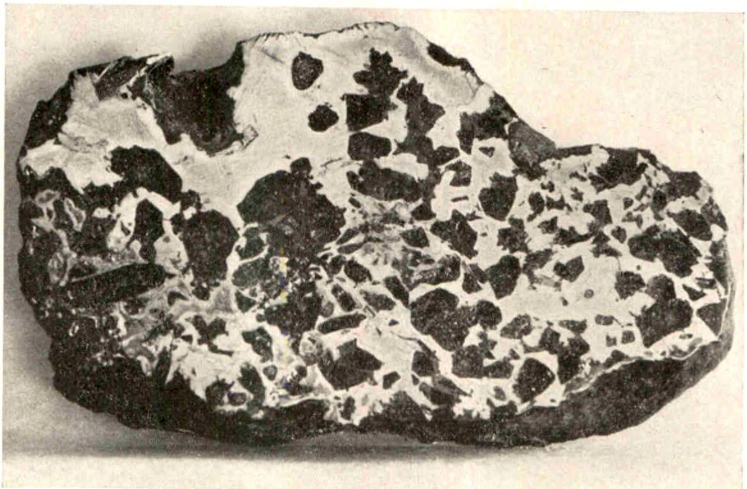


Fig. 1. Slice of Newport Pallasite, slightly reduced.

In July of the same year another fall was witnessed near the town of Miller only about 100 miles to the southwest of the Paragould fall. This gave a 36 lb. aerolite which has been reported by the American Museum. At about the same time there came to the writer a specimen of stony-iron meteorite which had been found in 1923 near the town of Newport, which is situated between the two stations just mentioned. Though the people who collected this specimen thought they had seen it fall there was no indication on its surface that it had recently fallen. Oxidation had penetrated to a considerable depth in places and the entire surface was covered by rust.

At the time the specimen reached me it weighed about 5,600 grams and seemed to be complete except for a small jagged area at one end from which it appeared a small mass had been detached. The person who sent the specimen reported that at the time it was "dug out" it was enveloped in a dark-colored shell or crust and weighed 28 lbs., and that this crust had been hammered off by the finders. From an examination of the surface I conclude that this crust must have been the soil

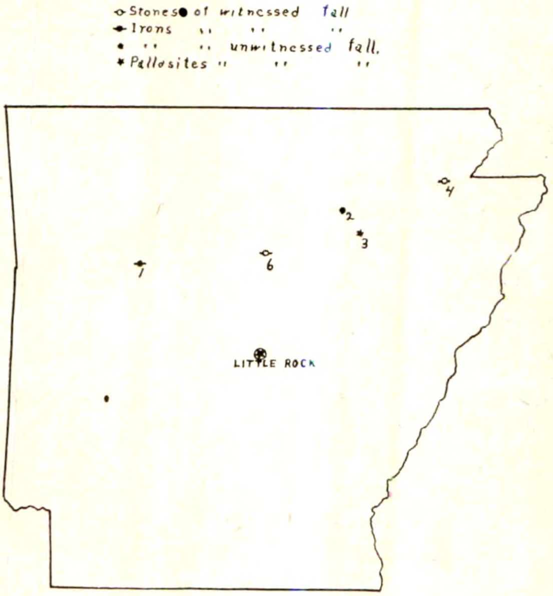


Fig. 2. Arkansas Meteorites. 1. Cabin Creek. Iron. Found 1875. 8.6 kgs. (19 lbs.). One mass. 2. Joe Wright Mt. Iron. Found 1884. 42.7 kgs. (94 lbs.). One mass. 3. Newport. Pallasite. Found 1923. 5.6 kgs. (12.5 lbs.). One mass. 4. Paragould. Stone. Fell 1930, Feb. 17, 4 a. m. 411.4 kgs. (905 lbs.). Four masses. 5. Western Arkansas. Iron. Found about 1890. 1.7 kgs. (3.7 lbs.). One mass. Location indefinite. 6. Miller. Stone. Fell 1930, July 13, 9 a. m. 16.7 kgs. (36.7 lbs.). One mass.

which had been penetrated by the iron oxide similar to what I have witnessed in the case of some of the Brenham pallasites. At any rate the surface of the Newport specimen at the time I received it had evidently not suffered any loss of its pallasite material except from the small area mentioned above. Sectioning revealed a typical pallasitic structure intermingled with areas from which most or all of the olivine was absent. The olivine inclusions are less rounded than those of the Brenham meteorite but not as angular as in the case of some other pallasites which have been described. The most striking inclusion is a cylindrical one whose length is five times its diameter. This cylinder was bisected in the process of cutting and shows in the accompanying figure. There is much irregularity in the size of the various inclusions, as the figure shows.

The metallic portion of this meteorite exhibits a distinct lamellar structure with the taenite quite prominent while the bands of kamacite are very irregular in width and the plessite relatively inconspicuous. Where the metallic bands are narrow the crystalline structure described is not revealed; but two distinct portions are clearly shown—a band of bright white metal bordering the olivine and a dark, porous area within. These areas are frequently given to exhuding lawrencite, which badly damages the specimens.

Troilite is quite abundant but is not equally distributed. It is usually found in nodules embedded within the metallic portion or lying between the olivine and the metal. It dissolves readily in HNO_3, and discolors the surrounding metal unless covered during the process of etching.

Schreibersite is found in irregular masses scattered about through the metallic portion.

It is noteworthy that this is the eleventh pallasite found on the continent of North America.

No chemical analysis has been made.

The meteorite shall be known as the Newport pallasite. The main mass is in the Nininger Collection of Meteorites.

Colorado Museum of Natural History,
Denver, Colo.

SCIENTIFIC INTELLIGENCE.

CHEMISTRY AND PHYSICS.

Elements of General Chemistry; by JOSEPH A. BABOR, WM. L. ESTABROOKE, and ALEXANDER LEHRMAN. Pp. x, 601; 134 figs. New York, 1931 (Thomas Y. Crowell Co., $3.75).—This book is intended as a text for students without previous chemical experience. It is in no way designed as a pandemic text; on the contrary, it offers the student a thorough foundation of basic chemical principles on which he may later, if he desires, base a pandemic course with proper understanding and profit. We stress this point, since the author states that his classes are subdivided according to whether or not they intend to go further in chemistry. The early chapters contain nothing which we feel should be omitted from any elementary chemistry course. Later, we do find certain chapters, and more or less fine print, which might be omitted by the general student without loss. This does not detract in any way from the usefulness of the text, as the arrangement permits such omissions to be made easily.

The book has a certain amount of general similarity to Babor's more advanced text, and contains a few more pages than its "grown up" relative. This fact finds its explanation, we believe, in the more detailed explanations and illustrations of the various theories for the benefit of the beginner. Although the text is the joint work of three, we cannot detect whether each has contributed different sections, or merely acted in an advisory capacity. The style is smooth throughout, and the book should be read with real interest. We do feel, however, that at several places we can recognize the direct influence of contemporary beginning texts.

The order of presentation of material does not differ widely from what we might term the standard order. The grouping of such apparently unrelated substances as chlorine and sodium hydroxide is novel, but finds adequate justification. In the metal section, we deal first with iron, then with the platinum group of metals. These diversions from type receive our hearty approval, as does the relegation of the sections on organic chemstry to the very end of the text. By that time, the student may be able to appreciate them.

Atomic structure receives early, and for the beginner, quite extensive treatment. Atomic diagrams are continually used to illustrate and explain chemical behavior. We know of no other text which employs this theory so usefully. Although both the cubical and "ring" diagrams are used, it is to be noted that neither one is set forth as being an attempt actually to picture the atom.

We are of the opinion that the theoretical sections, although well done, may cause the text to appear a little heavy for use in brief courses with few class-hours weekly. We doubt the value for beginners of the concept of pH values, and of the rather long chapter on radioactivity. The determination of molecular weights seems also a bit too detailed.

Each chapter is supplemented by quite a large number of review questions which are well chosen and afford a good cross section of the text content. Answers to numerical problems are generally included. There are an adequate number of explanatory figures. We feel that this text will be able to take a place among the rather large number of publications in the same field. E. B. KELSEY.

Laboratory Manual in Elements of General Chemistry; by Babor, Estabrooke, Lehrman. Pp. ix, 420 (one side); 42 figs. New York, 1931 (Thomas Y. Crowell Co., $2.00).—This manual has been prepared to accompany the "Elements of General Chemistry" by the same authors. Consequently the order of the manual is very closely correlated with that in the text. In an effort to maintain this close agreement, some experiments have been included which we believe to be rather pointless; such as, the experiments on bromic and iodic acids, ventilation, the mineral garden, to mention a few.

Most of the experiments are of the simple garden variety so generally found in beginning courses. This does not, however, constitute a criticism, since the field has been pretty well worked. A little quantitative work appears early in the text. These experiments are good in themselves, but we doubt the ability of any large proportion of beginning students to obtain sufficiently close results in some of them to be of value. We wish that more of this type of work could have been included later.

Many spaces are left in the printed pages, evidently for the insertion of temporary notes. This should be helpful if the student is encouraged to elaborate them after the exercise. Although the experiments adequately cover the material of the textbook, the manual does not impress us as ranking with the text in excellence.

E. B. KELSEY.

Electro-plated Chromium Coatings: The increasing use of chromium is most interesting. It is to the presence of this element that stainless steel owes its rust-resisting properties and within the last few years chromium electro-plating has largely superseded the use of nickel. Such a coating owes its value to the extreme hardness of the metal and to the possibility of securing it with a brilliant luster which resists the action of severe corrosive agents. The appearance of the surface, however, varies greatly with the conditions under which the deposit is made. Thus, for example, with a given current density one may obtain, by merely increasing the temperature of the plating bath, a matt deposit ranging in color from dark to light gray, or a deposit highly brilliant, even after hours of deposition, or a smooth and scanty deposit of bluish tinge.

Also by varying the current density at a given temperature, the hardness of a deposit, as measured by abrasion tests, may vary as much as forty-three times.

W. A. WOOD has recently added something to the findings of metallurgical investigations by an examination of these coatings by means of X-rays.

The problems which were peculiarly amenable to X-ray analysis were the formation of allotropic modifications of the metal, the determination of grain-size, especially when the particles were so small as to be beyond the limit of microscopic resolution, and the presence of small amounts of crystalline impurities causing a preferential orientation of the crystallographic axis of the grains with consequent lattice distortion.

A certain amount of controversy has arisen as to whether in addition to the normal body centered cubic form of chromium, a hexagonal modification can be obtained by electro-deposition with consequent alteration of the properties of the deposit. Bradley and Ollard found that chromium could consist of a mixture of these two allotropes, while Sillers following their recommendations could get no trace of the hexagonal allotrope.

Our author made deposits of chromium on chemically cleaned copper wires, using a lead anode, with various current densities and temperatures ranging from 13° C. to 70° C. The coated wires were then placed at the center of a circular camera and diffraction photographs made by use of the chromium radiation. He found that the result seemed to depend upon the kind of plating bath used. Thus with a bath composed of 25 per cent pure Cr_2O_3 and 1/4th per cent sulphuric acid, he could find no trace of the hexagonal form, thus confirming the conclusion of Sillers; but when he used a bath containing 1/4th per cent sulphuric acid and 50 per cent of chromic acid, reduced by the addition of a little sugar, he found the hexagonal allotrope mixed with the cubic in proportions varying with the current density and the temperature of the bath. It ceased to form, however, when the temperature approached 30° C. As stated, he found the amount varied with the current density. If the efficiency of the bath is defined as the ratio of the weight of chromium deposited divided by the amount which would have been deposited according to Faraday's law, he found that the efficiency was highest when the deposit was wholly cubic with a current density less than 100 m.a. per sq. cm., and that the efficiency was lowest when the proportion of hexagonal was a maximum at 220 m.a. per sq. cm. The efficiency increased and the amount of hexagonal decreased slightly as the current density was increased up to 750 m.a. per sq. cm.

It was assumed that a lattice distortion would result in a shift of the position of the maximum intensity of a diffuse diffraction line compared with the position of a sharp line of the normal lattice. Comparison of various photographs revealed no such spacing changes. The changes in breadth of the lines which were found were ascribed to the presence of particles less than 10^{-6} cm. in diameter.

The original paper shows three graphs plotting the breadth of the lines against the current density at temperatures of 30°, 50° and 70° C. The following points of interest appear from these diagrams. Assuming that the grain size varies inversely as the line breadth, a fact which is later demonstrated in the paper, it appears, first, that as the current density varies there is a point reached where the grain size reaches a maximum; secondly, that for current densities less than that for this maximum the grain size diminishes rather rapidly with decreasing current, while above this critical density this variation is far less marked, especially when the temperature is below 50° C.; thirdly, there is a general relation between the grain size and the nature of the deposit. Invariably the highly brilliant deposits go with the smaller almost amorphous grain sizes.

There is evidence that the first few layers of atoms are regularly arranged so as to reproduce in the thicker bright deposits this regularity as a flat type of grains. When this regularity is lost the matt type of deposit appears.—*Phil. Mag.* 12, 853, 1931.

F. E. B.

GEOLOGY.

A Descriptive Petrography of the Igneous Rocks. Volume I. Introduction, Textures, Classifications, and Glossary; by ALBERT JOHANNSEN. Pp. 267; 145 illustrations and frontispiece. University of Chicago Press, Chicago, 1931 ($4.50).—This book begins with a short introductory chapter in which the terms commonly used in describing and classifying the igneous rocks are defined. Chapter 2 deals in detail with the constituents of igneous rocks, and Chapter 3 describes the structures and textures. Both of these chapters are excellently illustrated, the photomicrographs being especially fine. Notable also are the portraits of the many eminent petrologists that add distinction to the pages of the book.

The remainder of the book deals with classifications, not less than 26 being described. It is true of many of these classifications, as Loewinson-Lessing said, that no one but their authors has used or developed them. No attempt is made to analyze them critically, as Professor Johannsen admittedly prefers to present them impartially, so as to give the student an unbiased choice. It is doubtful whether many students will be gratified with the choice thus offered them, if indeed they know enough to make a choice, in advance of the real familiarity with igneous rocks that they will acquire from Volume II when it appears.

The final chapter gives the author's own system of classification, which will be used in the forthcoming Volume II, where the various rock families are defined and their megascopic and microscopic characters are given.

The appendices make up an important and highly valuable part of the book (pp. 159-253). Appendix I, "Miscellaneous Definitions," defines the terms used in petrology, including many from foreign languages, chiefly German, and many that are obsolete. Appendix II, "Definitions of Textural Terms," defines the structural and textural terms. The entries are not limited to those pertaining to the igneous rocks, but include also those on metamorphic and sedimentary rocks, though these are not so exhaustive. For most of the definitions bibliographic references are given, generally on the first appearance of the terms in print. This lexical portion of the book also is handsomely illustrated by many excellent photographs and photomicrographs. ADOLPH KNOPF.

The Marion Expedition to Davis Strait and Baffin Bay. Scientific Results, Part 3; Arctic Ice; by EDWARD H. SMITH. Pp. x, 221; 122 figs. U. S. Treasury Department, Coast Guard, Bull. 19. Washington, 1931.—The study of floating ice and its movement has attracted increasing attention among oceanographers and the general public since the establishment in 1913 of the international ice patrol following the loss of the *Titanic.* The ice patrol has gathered a mass of valuable data concerning the movement and wastage of bergs near their southern limit—in the vicinity of the North Atlantic steamship lanes. In order to round out the knowledge thus gained, the *Marion,* a U. S. Coast Guard vessel, was sent to the region between Newfoundland and Baffin Bay to make observations on the ice at and near its northern sources. The scientific results of the expedition are set forth in a three-part publication, of which Part 1 deals with the bathymetry of Davis Strait, Part 2 with the circulation of the Davis Strait water, and Part 3 (the volume here reviewed), with ice drift from Davis Strait into the North Atlantic.

The careful organization and lucid phrasing of this report give it almost the character of a textbook on floating ice. The author distinguishes between floating ice of sea- and land-derivation and discusses the various types encountered. He then considers the character of Arctic glaciers, with special reference to the glaciers of Greenland and the manner in which they "calve" (form bergs).

The core of the report, dealing with the behavior of the floating ice, follows. After considering the factors of wind and current that control berg drift, the author finds that the chief route taken by the Arctic ice from Davis Strait is along the Labrador and Newfoundland shelves, and that the rate of drift varies up to 25 miles per day. Some of the bergs round Cape Race and waste away in shoal water south of Newfoundland, and some ground on the Grand Bank, but the greatest number drift southward past the eastern side of the Bank. Rarely they are sighted as far south as Bermuda and the Azores, but most waste away before they reach the fortieth parallel of latitude. The amount of sea ice discharged into the North Atlantic is vastly greater than that of land-[glacier-] ice, but the latter, in large bergs, endures for a longer time.

Seasonal variations in the amount of ice reaching the North Atlantic are brought about by variable combinations of wind, current, pack ice, and winter temperature. Minor deviations from normal can be predicted, but the occasional great iceberg seasons still come without warning.

Quantitative calculation results in the conclusion that the low temperature of the Labrador Current and other Arctic currents is primarily the result of low absorption of solar radiation in the north polar region, and only secondarily of the chilling effect of Arctic ice.

Students of oceanography and glaciology will find in this discussion a considerable mass of new data set forth in a thorough and stimulating manner. RICHARD FOSTER FLINT.

Memoirs of the Geological Survey of Canada: Memoir 166. *Geology and Ore Deposits of Rouyn-Harricanaw Region, Quebec;* by H. C. COOKE, W. F. JAMES, and J. B. MAWDSLEY. Pp. ix, 314, with figures, plates, and maps. Ottawa, 1931 (45 cents).—Describes an area in western Quebec south of the Canadian National Railway. The bedrock consists of representatives of the Keewatin, Timiskaming, and Cobalt series cut by various intrusives. The surface of this complex mass is beveled to a peneplane, which in turn is blanketed with extensive deposits of glacio-lacustrine varved clays and local accumulations of gravel and sand in the form of eskers, kames, pitted outwash, and dunes. Shorelines of some of the late-glacial Great Lakes are present. The relations of numerous sulphide, gold, and molybdenum deposits to the bedrock are discussed at length.

Memoir 167. Fort William and Port Arthur, and Thunder Cape Map-areas, Thunder Bay District, Ontario; by T. L. TANTON. Pp. 222; 1 fig., plates, and maps. Memoir 167. Ottawa, 1931 (30 cents).—Detailed description of an area on the north shore of Lake Superior, embracing an irregular upland developed on early pre-Cambrian crystallines, cuestas and mesas developed on warped and faulted late pre-Cambrian sedimentaries with interbedded intrusives, and lowlands presumably also underlain by late pre-Cambrian strata but now veneered with drift and deposits formed in glacial Lake Algonquin and the Nipissing Great Lakes. A lengthy section is devoted to economic geology, including deposits, formerly exploited, of silver, lead, zinc, copper, and iron.

R. F. F.

Natural Gas in Western Kentucky; by Willard Rouse Jillson. Pp. 190; 23 maps. Kentucky Geological Survey, Series VI, Vol. 38 (Frankfort, 1931).—A summary account of the occurrence of natural gas in the western counties, organized according to producing fields, with a brief statement of the geology of and production from each field.

The Borden (Knobstone) Rocks of Southern Indiana; by Paris B. Stockdale. Pp. xi, 330; 7 plates, 72 figs. Indiana Department of Conservation, Division of Geology, Publication No. 98 (Indianapolis, 1931).—A comprehensive stratigraphic discussion, with special regard to lithologic facies and sedimentation, of a group of lower Mississippian siltstones and shales that extend from the Ohio River northwest through western Indiana.

R. F. F.

Publications of the United States Geological Survey; Dr. George Otis Smith, Director. Recent publications of the U. S. Geological Survey are noted in the following list (see earlier, Vol. 21, pp. 467, 468).[1]

A List of the Publications of the U. S. Geological Survey. Pp. 231, May, 1931. This volume contains an impressive catalogue of the publications of the Survey from the First Annual Report of Clarence King in 1880 through to the early part of 1931. The Topographic Maps alone are not listed. The extent of the Survey publications here included is shown by the following summary: 51 Annual Reports, 55 Monographs, 165 Professional Papers, 826 Bulletins, 655 Water Supply Papers, 225 Geologic Folios.

Topographic Atlas.—Forty-seven sheets. Recently issued is a new map of the Chocorua Quadrangle. This embraces an area of 215 square miles in the White Mountains region; walkers will find this map of especial interest and value.

Professional Papers.—No. 162. *Geology and ore deposits of the Goodsprings Quadrangle, Nevada;* by D. F. Hewitt. Pp. ix, 158; 40 pls. (incl. 5 maps), 55 figs. ($1.15).—Since 1907 the Goodsprings district has become the principal source of zinc ores in Nevada; lead is also prominent, with gold, copper, nickel, cobalt less so. The ore deposits occur in rocks older than the Permian and by far the larger part in a zone scarcely 500 feet thick below the Pennsylvanian. Production is expected to go on for many years from this region. Of the mines, seventy-five have been carefully studied.

No. 163. *The significance of geologic conditions in Naval Petroleum Reserve No. 3, Wyoming;* by W. T. Thom, Jr., and E. M. Spieker, with a section on the waters of the Salt Creek-

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[1] Publications of the Survey may be obtained as follows: 1. Maps (usual price of each Sheet 10 cents) from the Director of the Geological Survey, a discount of 40 per cent on orders of $5.00 or more. 2. Reports: at the prices given, from the Superintendent of Documents, Government Printing Office, Washington. Remittance by money order in each case.

Teapot dome uplift, by HERMAN STABLER. Pp. v, 64; 30 pls. (incl. 10 maps), 19 figs. ($1.15).—This investigation of the "Tea Pot Dome Reserve" confirms the judgment reached at the time the Naval Reserve was leased, that it was not susceptible to serious loss by drainage to nearby wells.

No. 164. *The Kaiparowits region, a geographic and geologic reconnaissance of parts of Utah and Arizona;* by H. E. GREGORY and R. C. MOORE. Pp. vii, 161; 31 pls. (incl. 4 maps), 5 figs. ($1.05).—The area described covers several thousand square miles, chiefly grazing land. The geology and especially the physiography are discussed at length; coal is the only mineral deposit.

No. 165. *Shorter contributions to general geology, 1930.* Parts C, D, E have been issued, completing the volume. The subjects are: C. Geology of the eastern part of the Santa Monica Mountains, Los Angeles Co., California; by H. W. HOOTS. Pp. i-ii, 83-134; pls. 16-34 (incl. 3 maps), figs. 7-8 (75 cents). D. Geology of the Big Snowy Mountains, Montana; by FRANK REEVES. Pp. i-ii, 135-149; pls. 35-38 (incl. 2 maps), fig. 9 (20 cents). E. The Kaolin minerals; by C. S. ROSS and P. F. KERR. Pp. 151-180; pls. 39-43, figs. 10-11, with title page, etc., of the volume (15 cents).

BULLETINS.—No. 818. Geology and mineral resources of the Cleveland district, Ohio; by H. P. CUSHING, FRANK LEVERETT, and F. R. VAN HORN. Pp. vii, 138; 23 pls. (incl. 3 maps), 11 figs. (65 cents).

No. 819. *The Wasatch Plateau coal field, Utah;* by E. M. SPIEKER. Pp. vi, 210; 33 pls. (incl. 3 maps), 11 figs. ($1.30).—This is the most productive coal area in Utah, the annual output being nearly 5,000,000 tons. It is estimated that a total of 7,800,000,000 tons exist in beds 30 inches thick, and 13,000,000,000 in beds over 14 inches thick.

No. 820. *Nitrate deposits in southeastern California, with notes on deposits in southeastern Arizona and southwestern New Mexico;* by L. F. NOBLE. Pp. iv, 108; 19 pls. (incl. 1 map), 7 figs. (45 cents).—Many localities of nitrates have been studied, but none of commercial value. It is to be noted, however, that the deposit of kernite ($Na_2O.2B_2O_3.4H_2O$), at Kramer, California, is probably the richest borate deposit known.

Nos. 821, 822. *Contributions to Economic Geology* (short papers and preliminary reports), 1930. No. 821. Part I, Metals and nonmetals except fuels; G. F. LOUGHLIN and E. F. BURCHARD in charge. Pp. iv, 78; 18 pls., 9 figs. (50 cents). No. 822. Mineral Fuels; H. D. MISER in charge. Pp. iv, 100; 9 pls. (30 cents).

No. 825. *Microscopic determination of ore minerals;* by M. N. SHORT. Pp. vii, 204; 11 pls., 16 figs. (60 cents).

WATER SUPPLY PAPERS.—No. 620. Geology and ground-water resources of Western Sandoval Co., N. M. (35 cents).—No. 637. B. Ground-Water supply of Mimbres Valley, N. M. 637. C. Water power resources of the McKenzee R., Oregon (15 cents). 637. D. Geology and Water Resources of the Middle Deschutes R. Basin, Oregon. No. 638. A. Artesian Water Supply of Memphis, Tenn.

Papers on the Surface Water Supply in the Drainage Basins named below. These are grouped geographically.—North Atlantic Slope. Nos. 641, 661, (35 cents each). South Atlantic Slope, Eastern Gulf of Mexico. No. 642. Western Gulf of Mexico (20 cents each).

Hudson R. and Upper Mississippi R., Nos. 645, 665 (20 cents each). Lower Mississippi R., No. 667 (15 cents). St. Lawrence R., No. 664 (20 cents). Ohio R., No. 643 (35 cents). Missouri R., No. 666 (35 cents).

The Great Basin. No. 670 (20 cents). Colorado R. No. 669 (20 cents).

Pacific Slopes, California. Nos. 651, 660, 671, 691 (45 cents each).

North Pacific Slope, Washington, Upper Columbia R. No. 652 (20 cents), No. 672 (25 cents). Snake R. No. 653 (35 cents), No. 673 (25 cents). Oregon, Lower Columbia R. No. 654 (20 cents), No. 674 (25 cents).

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

An Introduction to the Literature of Vertebrate Zoology. Based chiefly on the Titles in the Blacker Library of Zoology, the Emma Shearer Wood Library of Ornithology, the Bibliotheca Osleriana, and other libraries of McGill University, Montreal. Compiled and edited by CASEY A. WOOD. 4to. Pp. xix, 643. Frontispiece in color. London, 1931 (Oxford University Press, price $15.00 or 3 guineas).—The thanks of all interested in the natural history of vertebrate animals are due to the compiler of this great work. A large proportion of the world's important titles are listed in its pages. The Blacker Library of Zoology aims to supply literary material "that will meet the varied wants of a University in which not only the student body, but research scholars, librarians, and the public generally may consult quickly nearly every work on zoology likely to interest them." The Wood Library of Ornithology is rich in complete sets of periodicals and serials devoted to bird-life in many languages. The Osler Library, collected and donated by Sir William Osler, was formed especially to illustrate the history of medicine. A large number of oriental works on zoology are contained in the Gest Chinese Research Library. The Lyman Library of Entomology and the general University library include many valuable zoological treatises and periodicals. It is therefore apparent that abundant material was available to the compiler and his collaborators.

The book embraces three main sections. *A, Introduction to the Literature of Vertebrate Zoology* contains 19 chapters whose headings may well be abbreviated here as follows: I. Beginnings of zoological records. Early Greek, Roman, and Oriental zoologists. Earliest medieval writers on vertebrate zoology.—II. Medieval writers on zoology and immediate successors. Zoological incunabula.—III. Renaissance and effect on records of zoological science. Publications of natural history societies and museums throughout the world. Some 16th and 17th century writers on vertebrate zoology.—IV. Literature of comparative zoology. Systematic classification of vertebrates. Darwinism, its literature, advocates, and critics.—V. Travelogues of explorers. Reports of voyages and scientific expeditions containing descriptions of vertebrates. Journeys of naturalists round the world. Government and private surveys and explorations.—VI. Forerunners, contemporaries, followers, and successors of Linnaeus. Short account of Linnean literature. Faunal classifications and nomenclature.—VII. Some fundamental titles in the literature of modern vertebrate zoology. Hand-colored atlases and their makers. Animal painters and illustrators.—VIII. From natural philosophy to modern biology. Literature of vertebrate zoology from A.D. 1750 to 1850.—IX and X. Some important zoological treatises and serials published during the Nineteenth Century. Monographs on local faunas. Textbooks on zoology. Reports of explorations and surveys. The literature of vertebrate bionomics.—XI, XII, XIII. Some important treatises and monographs on ornithology and mammalogy published during the 19th and 20th centuries.—XIV. The literature of zoogeography. Vertebrate ecology, and paleontology. Animal psychology. Zoological gardens, museums, and stations.—XV. Important treatises on ichthyology from the earliest times to the present.—XVI. Selected titles from the literature of herpetology and amphibiology.—XVII. Oriental literature on vertebrate zoology. Codices, printed treatises, and lithograms in Persian, Arabic, and other islamic languages. Sanskrit and Sinhalese writings. Chinese and Japanese literature on zoology.—XVIII. Periodicals and serials on vertebrate zoology.—XIX. Unique and rare printed books, manuscripts, and drawings in the zoological libraries of McGill University.

Section B in 20 pages presents a very convenient *Students' and Librarians' Ready Index to short Author-titles on Vertebrate Zoology arranged Geographically and in Chronologic Order.* This index is provided with an index of its own and instructions as to its use.

In section C, *A partially annotated Catalog of the Titles on Vertebrate Zoology in the Libraries of McGill University,* the reader will find 468 pages of titles in many languages. It is essentially an author's catalogue, chronologically arranged. Only independent publications are, as a rule, entered in this catalogue. The compiler found it impossible to record the 20,000 pamphlets, separates, and reprints.

Throughout this excellently constructed volume the type is clear and well suited to the various purposes. S. C. B.

Das Pollersche Verfahren zum Abformen an Lebenden und Toten sowie an Gegenständen; by ALPHONS POLLER (given out by E. B. Poller and E. Fetscher with a foreword by C. V. Economo). Pp. xii, 216; 129 figs. Berlin, 1931 (Urban & Schwarzenberg, 12 Mks., bound 14 Mks.).—This book, describing a method of casting from life with a new material originated and patented by Dr. Potter, is of decided interest.

The material used is called negocoll, a hydrocolloid which, like gelatine, is dissolved in water. The object of the method is to do away with the oiling, or greasing of the skin or tissues, preventing the pulling of the hair and producing the skin abrasions usually incumbent upon the use of plaster in all but very skilled hands. It also eliminates the irregular quality of various makes of plaster. In other words, the main object seems to be to make good casting possible for the occasional practitioner.

Its use permits the casting of such delicate parts as the open eye, impossible to cast in plaster. It is elastic and in casting such parts as a hand or foot in the round, a layer of thin material, one-half inch thick when set, can be pulled off like a glove and still retain the shape and position required without the assistance of a backing or shell.

Dr. Potter also claims that a much finer quality of detail is obtainable. It eliminates dust and does not create any dirt as does plaster. Since it is absolutely sterile and antiseptic, it is suitable for use in casting open wounds, internal, and even dental work.

It is produced in two grades, one called negocoll and the other dentocoll. The latter is used for medical purposes because of its higher temperature of solubility. The former has a melting temperature slightly above that of the body as it is applied at about 50 degrees. It can be kept indefinitely since it does not decompose like glue.

This is a very good medium and method for anthropologists, anatomists, criminologists, etc., but it is to be doubted whether it is especially practical for sculpture work, unless it is used for making casts of the living model to be used for reference and that is seldom done. Another objection on the part of the sculptor might be that it requires a much greater range and variety of tools and equipment, than is generally used in the studio in order to obtain satisfactory results.

There is, however, no question as to its absolute truth in reproduction, but it is essentially a method for students in surgery and for reproduction under unusual conditions. For the sculptor it answers the purpose of the gelatine, or glue mould. However, one would need to try it in this respect in order to find out how many replicas of the original could be cast from one mould.

R. G. EBERHARD.

The National Academy of Sciences.—The autumn meeting of the National Academy of Sciences was held at New Haven, Conn., on November 16, 17, 18. Some sixty members were present. Scientific sessions were held in the Sterling Chemistry Laboratory on Monday (16th) and Wednesday (18th); also in the Sterling Hall of Medicine on Tuesday (17th). Fifty-seven papers in all were included in the program.

The dinner of members and guests was held on Tuesday evening at the New Haven Lawn Club. In connection with this occasion, two gold medals were presented. The first was the Draper Astronomical Medal presented to Dr. Annie Jump Cannon, Curator of Harvard Observatory. This was in recognition of her remarkable work, extending over many years, in the classification of stars by their photographic spectra. Her catalogue of 225,000 stellar spectra fills nine octavo volumes of the Harvard Observatory Annals. The Agassiz Medal for Oceanography was presented to Professor Henry Bryant Bigelow of Harvard University and Director of the Oceanographical Institute at Woods Hole, Massachusetts.

Tributes were also presented, at the dinner, by Professors Charles Schuchert and Richard Lull to the paleontologist, Othniel Charles Marsh (1831-1899), who was the President of the Academy from 1883 to 1895. His great collections, largely in vertebrate paleontology, are now preserved in the Yale Peabody Museum. The following resolution was adopted: "That in this year which marks the centenary of the birth of Othniel Charles Marsh, and in the environment where he lived and worked so long, the Academy recalls with pride the personality and mental gifts of that great paleontologist, whose distinguished service as its president was entirely in keeping with a lifetime of uninterrupted devotion to Science."

PUBLICATIONS RECENTLY RECEIVED.

Carnegie Institution of Washington. News Service Bulletin. Volume II. Numbers 23, 24. An Evolving Universe. Part I.—Innumerable Star Systems; Part II.—States and Stages in Development.

Field Museum of Natural History. Chicago, 1931. GEOLOGICAL SERIES. Vol. IV, No. 6. Occurrence of the Alligatoroid Genus Allognathosuchus in the Lower Oligocene by Bryan Patterson.—No. 7. A Silurian Worm and associated Fauna; by Sharat K. Roy and Carey Croneis.—No. 8. A Fossil Turtle from Peru; by Karl P. Schmidt. BOTANICAL SERIES. Vol. VII, No. 4. The Rubiaceae of Venezuela; by Paul C. Standley.—Vol. XI, No. 3. The Nyctaginaceae and Chemopodiaceae of Northwestern South America; by Paul C. Standley. Field Museum News. November, 1931.

Recent Advances in Physical Chemistry; by Samuel Glasstone. Philadelphia, 1931 (P. Blakiston's Son & Co., $3.50).

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Cours de Physique; by Ch. Fabry. Tome I. Quarto. Paris, 1932 (Gauthier Villars et Cie, 150 fr.).

Contributions in Geology; edited by Chester K. Wentworth. Washington University Studies—New Series. Science and Technology—No. 5. St. Louis, 1931.

An Introduction to Organic Chemistry; by John Read. London, 1931 (G. Bell and Sons, Ltd., 6s. 6d.).

Quantitative Chemical Analysis; by Frank Clowes and J. Bernard Coleman. Revised by D. Stockdale and J. Dexter. Thirteenth Edition. Philadelphia, Pa., 1931 (Blakiston's Son & Co., $5.75).

The New Conceptions of Matter; by C. G. Darwin. New York, 1931 (The Macmillan Company, $3.00).

Lehrbuch der Mikrophotographie und Mikroprojektion; by Dr. med. Kurt Laubenheimer. Zweite Auflage. Berlin, 1931 (Urban & Schwarzenberg, 18 Mks., 20.40 Mks., bound).

Colloid Chemistry, Theoretical and Applied; by selected International Contributors. Collected and Edited by Jerome Alexander. Volume III. First Series of Papers on Technological Applications. New York, 1931 (The Chemical Catalog Co., $10.50).

OBITUARY.

DR. CHARLOTTE ANGAS SCOTT, until recent years professor of mathematics at Bryn Mawr College, died on November 8 at the age of seventy-three years. She was the first woman wrangler in the University of Cambridge, England.

DR. WILLIAM TUDOR GRISWOLD, civil engineer and geologist, died on November 30 at the age of seventy-two years. Beginning in 1881, he was connected with the U. S. Geological Survey for twenty-three years, chiefly doing topographic work. He also devoted himself to the development of oil and gas in this country, Mexico and Colombia.

DR. CLARENCE LEMUEL ELISHA MOORE, professor of mathematics in the Massachusetts Institute of Technology, died on December 5 at the age of fifty-five years.

DR. EDWARD STEP, prominent in entomology and natural history, died on November 8 at the age of seventy-five years. He had been for more than fifty years a member of the South London Entomological and Natural History Society.

DR. GUIDO HOLZKNECHT died recently in Vienna at the age of fifty-eight years. His study of X-rays began very early and continued through his life, yielding important results in pure science as well as therapeutics.

THOMAS ALVA EDISON

To the man in the street Edison was a wizard; to the man of science he was something short of this but nevertheless a genius in his mechanical ingenuity and his almost unparalleled ability for assiduous application.

His career does not show that he owed his successes so much to happy circumstance, as to his ability to seize each opportunity to advance his knowledge, as occasion presented itself.

Thomas Alva Edison was born at Milan, Ohio, February 11, 1847. When introduced into the public school of Port Huron, to which his father had moved in 1854, he was found to be so backward that after three months his mother took him out and continued his education under her own direction. He early showed a predilection for chemical and physical experimentation. At the age of thirteen his father permitted him to become a railroad newsboy that he might earn money to continue his experiments. During this period Edison was so fortunate as to have been able to save from death the child of a station agent on the railway and in gratitude this agent offered to teach the boy telegraphy. He soon became one of the most rapid and efficient telegraphers of his day.

By the time Edison was 22 years of age he had invented the duplex system of telegraphy, later to be expanded into the quadruplex and multiplex systems, and a stock ticker, for the rights in which he received $40,000. With this money he was enabled to build a factory and a laboratory and started on the career which made him famous.

By far the most important scientific discovery of Edison was the effect which has since borne his name. In 1883 he observed that when he heated the filament of an incandescent lamp to a certain temperature, a blue glow appeared between the legs. To satisfy his curiosity he inserted a wire into the bulb. When this wire was connected to the positive terminal of the lamp a current flowed through it but when the connection was made to the negative terminal no such current could be detected. Edison himself made no use of this observation. but Fleming in 1905 evolved from it the valve, or two-element rectifier, which laid the foundation for wireless telegraphy, and the following year deForest introduced a grid by which small fluctuations of the potential on the grid were reproduced in the plate current. It was this device which made possible the truly miraculous developments in radio broadcasting, in trans-Atlantic telephony, and in television. So near did Edison come to unexampled fame.

His greatest invention was probably his discovery of the way to preserve the spoken word by means of the phonograph, which he first constructed in 1877. Usually the honor of a great invention has to be shared with various others who have contributed to the thought. In this case, however, Edison may claim all the honor as strictly his own.

In his other great achievements the fame does not belong to him alone. For instance, he is commonly credited with the invention of the incandescent lamp, when after much experimenting he made a successful filament by carbonizing a thin strip of bamboo. This was first publicly shown in October, 1879. It is, however, a matter of record that Swan in England had publicly shown a vacuum lamp with a carbonized filament in February of the same year.

Edison was by far the leading spirit in the development of the lamp industry in America, but incandescent lamps would have come if there had been no Edison, for to-day the filament of lamps, universally used, is made of tungsten, the idea of its use originating apparently in Germany. He does, however, deserve great credit for his design of constant potential dynamos, central power stations, and systems of distribution.

In April, 1877, Emile Berliner filed a caveat on a device for a telephone transmitter in which the vibrations of a diaphragm caused the contact resistance between two metallic points to vary as the result of a change of pressure at the contact, and thereby to produce a fluctuation in a current passing through the system. In the same year Edison working independently discovered that he could produce varying currents by a similar variation of pressure on a carbon button. The priority of this invention, or more particularly the question as to whether Berliner's invention was limited to metallic contacts and Edison had contributed something different by using carbon, was bitterly fought in the courts for many years. It appears that the Berliner patent finally won out and that Edison just missed by a few months the great distinction of being the discoverer of the principle of the microphone.

Another idea of Edison's was that pictures of a moving object could be taken in rapid succession and later flashed on the eye so that they fused into a representation of the original action. In 1887 he constructed a machine on this principle which was put on the market in the form of a peep-show, but he opposed the idea of projecting the pictures on a screen as he thought it would ruin his peep-show business. He also thought of combining the motion picture with the phonograph and worked in 1912 on the idea of a talking picture but though he failed to introduce it commercially because the phonograph had not then reached its present perfection, he still must be regarded as the father of the talking picture.

From 1900 to 1910 his chief interest centered on the idea of realizing a storage battery which did not use lead, and should contain an alkaline solution instead of an acid. This proved to be the hardest nut he ever tried to crack. It is said that he tried 50,000 experiments before he achieved his goal in the construction of a nickel, iron and caustic potash cell. Although it was at one time considerably used for running automobiles it has now disappeared, one fault being the large temperature-coefficient. When the temperature falls the E.M.F. also diminishes so as to make it inoperative.

It is probably not too much to say that Edison was the greatest inventive genius that ever lived. During his life he took out no less than 1,150 patents and his inventions covered practically all fields of science.

Edison was purely an empiricist. His method was by persistent trials and experiments, often performed at random, testing all available materials, to attain the result he was looking for. This method was inefficient in the extreme, for his labors might have at least been cut in half, if he had been willing to be guided by theory and helped by calculation, but like most self-educated men he looked askance at book-learning and mathematical theory. His actual achievement was prodigious but the recurrence of a phenomenon like Edison is extremely improbable. Scientific research in the future will be for the most part carried on in large laboratories and by a staff of experts.

There is no doubt that the life of Thomas A. Edison has been one of the most useful in all history to world civilization. His influence in bringing benefits and comforts to mankind was immeasurable. Science and humanity have sustained a great loss in his passing.

FREDERICK E. BEACH.

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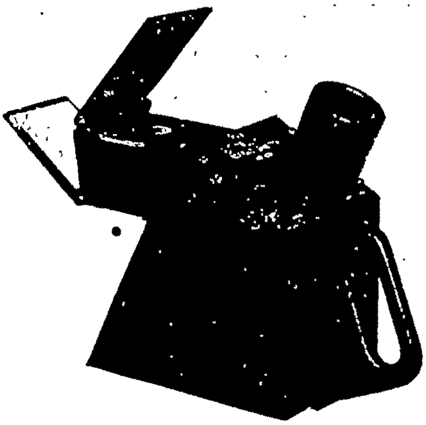

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KANSAS PERMIAN INSECTS. PART 15. THE ORDER PLECTOPTERA.

R. J. TILLYARD.

[Studies aided by a grant from the Marsh Fund of the National Academy of Sciences.]

The order Plectoptera or Mayflies is very well represented in the Yale Collection of Lower Permian fossil insects from Kansas, there being ninety-two specimens present. About one-third of these may be said to be in really good condition, another third in a state of medium preservation and the remainder are very poorly preserved. Most of the specimens consist only of wings or parts of wings; only four are more or less complete specimens of the insects.

Probably no order of insects has had more interpretations given to its wing-venation than the Plectoptera. The first really comprehensive study of the order was made by Eaton (1883-1886), more than a decade before the historic publication of the series of papers by Comstock and Needham (1898-1899) which formed the basis of their theory of venational nomenclature. Eaton evolved his own system, like other workers on other orders of his time—without any conception of a scheme which should be applicable to all winged insects alike—and a remarkably good system it was, too; so good that, even at this day, his detailed descriptions may be read with a clear understanding, while his classification has formed the basis of all subsequent taxonomic work on the order.

It is interesting to note that Eaton used, for the first four veins of the wing, the terms which were subsequently adopted by Comstock and Needham, viz. *costa, subcosta, radius* and *sector*. After the sector, however, he uses the following names in order: *cubitus, praebrachial, pobrachial, anal* and *axillaries*. Of these we observe that two are no longer in use, while one, the cubitus, has been adopted by Comstock and Needham for a different vein altogether.

Following Eaton we come next to Comstock and Needham's original attempt (1899) on the homologies of the wing-veins of the order. As this interpretation was later on abandoned in favor of Miss Morgan's interpretation (1912), it is not necessary to discuss it very fully, though it includes some points of considerable interest. We should note, however, that the authors fully recognized the importance of the division of the basal tracheal supply of the developing nymphal wing into two main groups, the *costo-radial* and the *cubito-anal,* but failed to apply it correctly to the imaginal wing; a failure in which they were later on followed by Miss Morgan herself. Actually, Comstock and Needham's original interpretation of the homologies of the mayfly wing was far closer to the truth than the later interpretation which they accepted from Miss Morgan. In particular, we should note that these authors quite correctly fixed the limits of the radial sector at their first attempt.

Ann H. Morgan (1912), evidently filled with enthusiasm for the then greatly admired theory of Needham (1903) concerning the supposed "crossing-over" of the radial sector in Odonata to a position posterior to the two anterior branches of the media, sought to apply the same idea to the mayflies. In this she succeeded to her own satisfaction, having discovered, after many hundreds of dissections of mayfly nymphs, a solitary species (*Heptagenia interpunctata*) in which such a tracheal crossing appeared to be *sometimes* present. Nothing more unstable in the way of tracheation than that of the nymphs of this group could very well be imagined; yet, so powerful was the guiding principle in her mind, that the author selected at once this small chance variation as of the utmost phylogenetic significance, and proceeded to interpret the venation of the mayflies along lines exactly parallel to Needham's famous interpretation of those of the Odonata. Quite apart from the fact that the fossil evidence now accumulated in the Odonata has effectively disposed of Needham's theory of the crossing-over of Rs in that order, Miss Morgan overlooked another small point, emphasized later on by Martynov (1923), viz. that the vein entered by the crossing trachea in the *Heptagenia* nymph is not homologous with the vein entered by it in Anisopterous Odonata, the former being a concave and the latter a convex vein!

Another decade had to pass before the next advance in this subject was made, through the statement of Lameere's general theory of wing-venation (1922), in which, for the first time, the presence of two distinct elements was recognized in the primitive formation of the median vein, viz. the *convex anterior*

median, MA, and the ***concave posterior median,*** MP. Working with a knowledge of Lameere's theory, Martynov (1923) next produced a very valuable paper on the venation of dragonflies and mayflies, in which he applied Lameere's theory to the latter order, but for some reason reached the remarkable conclusion that MA had entirely disappeared in this order. As Martynov's paper has only recently become known to English readers, through the publication of an English translation from the Russian by Miss Olga Jahr and Dr. F. M. Carpenter (1930), it seems advisable to leave a full discussion of his theory until later in this paper.

Working independently in New Zealand, and, at the time, without any knowledge of Lameere's paper (which only reached me after my own paper had been mailed to London for publication in March, 1922), I published in 1923 a paper in which I made an attempt to correlate the evidence from the Lower Permian fossil Plectoptera, at that time recently received by me, and the nymphal tracheation of certain archaic New Zealand genera such as *Oniscigaster, Ameletus* and *Coloburiscus.* In this paper I figured the complete venation of both the fossil genus *Protereisma* Sellards and the recent genus *Ameletus* Eaton, and showed that their venations were strictly homologous. The interpretation, based partly on this fact and partly on the results of dissections of several nymphal instars of recent forms, unfortunately left out of account the vein MA, Lameere's work being then unknown to me, and thus allocated to the radial sector, not only all the branches properly belonging to it, but also the triad of MA. Later, however (1926), when Lameere's work had become known to me, I corrected this error and recognized that the convex vein which I had previously considered to be R_{4+5} could not be a true part of the concave Rs, but represented the true MA of Lameere which had become secondarily fused with Rs basally. In this last attempt, I was content to leave the notation of the posterior or concave portion of the media as M, following strictly the notation of Comstock and Needham. I would now, however, make this alteration in my scheme of venational nomenclature for the order Plectoptera, viz. that the concave median should be properly designated as MP.

There are, then, two interpretations of mayfly venation which hold the field at the present time, viz. Martynov's of 1923 and my own of 1926 with the above slight emendation. Though Martynov's interpretation is the older, it is presented to English readers as the newer owing to its very recent translation from the Russian, and has, therefore, to be treated as entirely new.

It was very unfortunate that Carpenter did not see fit to include Martynov's figures in the translation of his valuable paper. The originals are not available to me, and not likely to be, and I doubt if they are available to more than a few favored individuals in English-speaking countries. While there are plenty of figures available of the wings of the genera mentioned by Martynov, there are none with his labelling of the veins, and it is, therefore, not easy to follow all the minute points of his reasoning, in which his figures are frequently referred to. No doubt this point did not seem so important to Carpenter, working with the figures in front of him, as it does to someone who is compelled to work without them. For this reason, it will be necessary for me, while discussing Martynov's paper, to use complete quotations from it more often than I otherwise should have done.

It has to be borne in mind, also, that Martynov, when writing his paper, did not have my paper of 1923 before him. Our ideas have been evolved quite independently, and I believe that this is the first time that they have been subjected to critical comparison.

The main point on which Martynov and I differ is on the vital question as to the presence or absence of the true anterior median, MA, in Plectoptera. Martynov's position may be stated as follows:

(1) The ancestral type of venation from which those of both Odonata and Plectoptera (which he calls Agnatha) are derived is that found in the Carboniferous fossil family Dictyoneuridae of the order Palaeodictyoptera.

(2) The Carboniferous genus *Triplosoba* Brongn. (Fig. 1), placed by Handlirsch in a special order, Protephemeroidea, preserves the venational features of the Dictyoneuridae and also agrees exactly with fossil and recent Plectoptera.

(3) We must, therefore, determine the correct homologies of the veins in Plectoptera by reference to the Dictyoneuridae and to *Triplosoba.*

He then draws the following conclusion:

"(In *Triplosoba*) M, as in the Dictyoneuridae, is divided near the base into the same two branches, MA and MP; MA also, as in the Dictyoneuridae, remains simple, while MP is divided distally into three branches, the middle one and two supplementary ones beside it being already changed into 'inserted sectors' (Schaltsectoren). The close similarity of this MP with M in the real Ephemerids leads us to believe that M of the may-flies is really MP, and their MA is reduced and has completely vanished."

And again, a little later in the same paragraph:

"As already mentioned, the fore and hind wings in the may-flies of the Permian were alike, their shapes quite resembling those of the Dictyoneurid wings; but in all that is known to us, MA was already missing."

Is this conclusion justified?

First of all, in case I have completely failed to gather Martynov's argument owing to the absence of his figures, I follow once again carefully through his account of the radial sector; for on that depends (when we have no figures to guide us) our correct placing of Martynov's media. I find his description of vein Rs both in Dictyoneuridae and in *Triplosoba* to be unequivocally clear; there is a basal group of two branches (evidently his RS$_4$ and RS$_5$, equivalent to my IR$_{3b}$ and R$_{4+5}$ respectively), and a well-removed distal triad, consisting of his RS$_1$, RS$_2$ and RS$_3$ (equivalent to my R$_2$, IR$_2$ and R$_3$ respectively). Though he apparently does not mention the triad developed at the end of R$_3$ in true Plectoptera, yet he says quite definitely: "The branches RS$_4$ and RS$_2$ represent 'inserted sectors', as in the recent Ephemerids." There can, therefore, be no doubt as to which veins are here meant, seeing that neither the Dictyoneuridae nor *Triplosoba* possessed a triad on R$_3$.

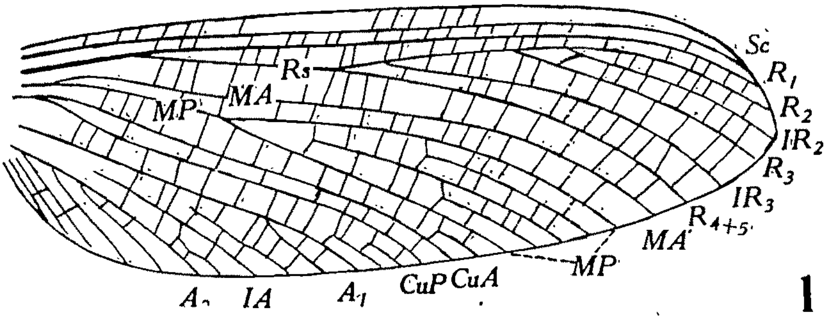


Fig. 1. Wing of *Triplosoba pulchella* Brongn. Order Plectoptera, Suborder Protephemeroidea. Enlarged and adapted from Handlirsch, with venational notation as adopted for the order Plectoptera in this paper. (See Table on p. 111.)

We are, therefore, again driven back to Martynov's statement that MA is absent, and that, therefore, the vein following next to Rs in order posteriorly is MP. ***But this vein, both in the Permian fossil Plectoptera and in all recent forms, is a*** convex ***vein.*** How then can it possibly be Lameere's posterior median vein MP, which is *concave?*

Apart from this to me inexplicable oversight on Martynov's part, it seems clear that he has been misled by the logic of his argument. Firstly, who decided that the Dictyoneuridae possessed the most primitive type of venation? Secondly, who decided that *Triplosoba* was ancestral to the true Plectoptera? In accepting these two branches, Martynov has accepted some obvious errors.

The trouble appears to be that, in *Triplosoba* (Fig. 1), the vein that is obviously MA is a simple vein. The Dictyoneuridae also have this vein simple. But there are many Palaeodictyoptera in which it is branched, and ***some even in which it has developed a distal triad exactly as in Plectoptera,*** e.g. *Homaloneurites.* Even, then, if we grant that *Triplosoba* is descended from Dictyoneuridae, which I am not prepared to grant myself, why is it necessary to go a further step and to eliminate the simple vein MA, simply because the mayflies do not possess this simple vein?

A little further reflection will help us. In *Triplosoba,* although MA happens to be a simple vein, an examination of the complete vein M shows us that it possessed six branches, of which, according to Handlirsch's figure, five belonged to MP. Putting aside the possibility that this figure is wrongly drawn (and this possibility must not be lost sight of, seeing that a double triad of the type shown in Handlirsch's Atlas, Figure 7, Plate xxxii on vein MP must be almost unique, and besides is not indicated on his Figure 6 of the same insect), it might be suggested that *Triplosoba* was perhaps not in the direct ancestral line of the true Plectoptera, but was a representative of a side-branch (comparable with the Protodonata as against the true Odonata), in which the media underwent a different type of branching.

A further difficulty awaits us if we accept Martynov's statement that MA is absent. For this immediately throws out of gear the complete alternation of convex and concave veins which we meet with more perfectly developed in mayflies than in any other order; and therefore, if MA is absent, ***there must also be some other*** concave ***branch of a main vein absent,*** to restore the complete series of alternations, as has happened in the Odonata, where the loss of MP balances the loss of Cu_1. Yet Martynov continues to develop his theory of the venation of mayflies by accounting for all the usual veins posterior to MP. Let us now see into what further difficulties this leads him.

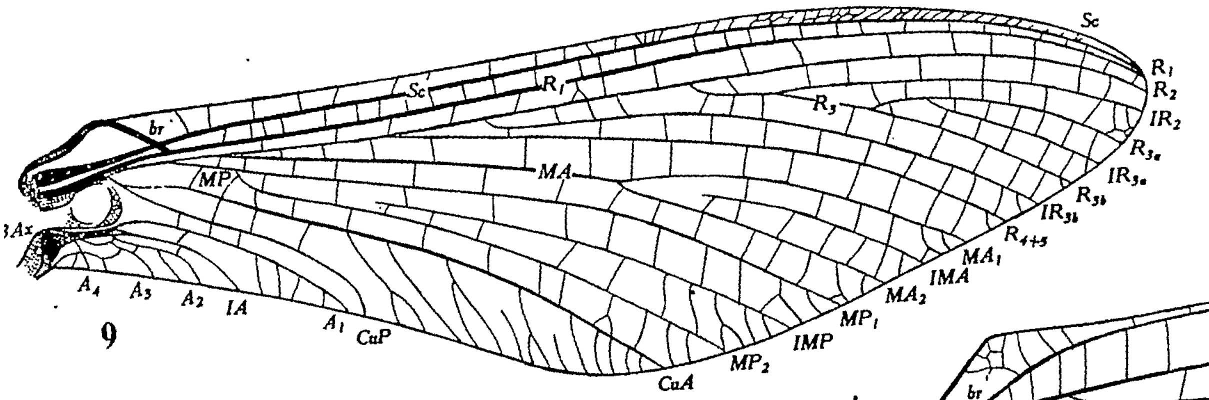
He says (p. 255 of English translation of his 1923 paper), referring to the Lower Permian forms: "The homologizing of the veins in these last forms with those in the Dictyoneuridae is therefore not difficult and is correctly interpreted by Handlirsch." This gives us a definite clue to his own interpretation. Turning to Handlirsch's figure of the venation of *Palingenia* (Atlas, Pl. iv, Fig. 20), we there find that the vein which I interpret as MA is labelled M and is obviously the MP of Martynov, in spite of the fact that it is a convex vein; this is followed posteriorly by the vein which I call MP and which both Martynov and Handlirsch consider to be Cu. Of this vein, Martynov says: "Cu arises near M and soon divides into two main branches, Cu_1 and Cu_2, with an inserted middle branch which joins at the base either to Cu_1 or Cu_2 ('inserted sector')." Now Martynov has elsewhere stressed the fact, first observed by Lameere, that the formation of the three main veins R, M and Cu is similar, i.e. each vein is composed of an anterior *convex* branch and a posterior *concave* branch. In the radius, these parts are R_1, convex, and Rs, concave; in the media, MA, convex, and MP, concave; in the cubitus, CuA, convex, and CuP, concave. Yet, even in so highly specialized a type as *Palingenia*, it is very easy to verify the fact that the vein determined as Cu by Martynov and Handlirsch is ***purely a concave vein with two concave branches and an interpolated convex vein between them.*** In other words, it must be either MP or CuP ***with a very deep negative triad developed on it.*** A comparison of *Palingenia* with some more primitive type, such as *Tasmanophlebia* (Fig. 9) shows us at once that the triad on this vein steadily approaches nearer to the base as we ascend the evolutionary series. A further comparison between *Tasmanoplebia* and *Protereisma* (Fig. 14) supports this view. Finally, a comparison between *Protereisma* and *Triplosoba* (Fig. 1) shows that the triad in question can be none other than the triad developed on the vein called MP in this genus by Martynov. From this point, we deduce the further consideration that the simple convex vein MA of *Triplosoba* is present in all true Plectoptera, fossil and recent; but, instead of being a simple vein, *it has a positive triad developed on it, arising near the middle point of the wing.*

However, it appears on reading further that Martynov himself is not quite sure at this point, for he says (p. 256): "It is difficult to say yet if one can see in our Cu_1 and Cu_2 of the Ephemerids CuA and CuP. The similarity with the dragonflies seems to confirm it, but their palaeontological data do not assert this with certainty, and I indicate these branches so far by different symbols." One gathers also from other remarks that Martynov had not then seen any figure of *Protereisma* with the cubito-anal region sufficiently well drawn to warrant him making more definite conclusions; and, indeed, Sellards' figures were at that time the only ones which were available to him.

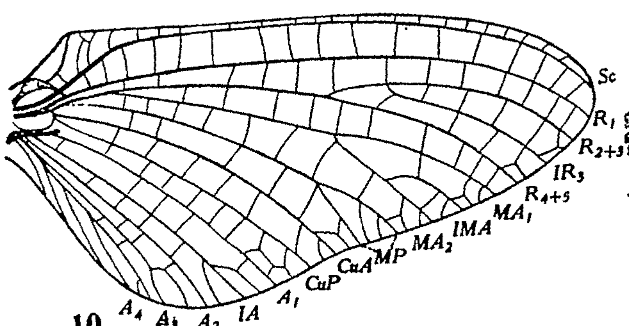
Now we may ask at this point, how can we make certain that this vein which we are discussing is MP, and not either the entire Cu, or alternatively CuP? I think there are two very compelling reasons, which I will now give:

(1) *The Evidence from the Venation of Fossil and Recent Plectoptera:* More than in any other order, the complete set of alternating convex and concave veins is preserved in the Plectoptera. If, then, we follow Lameere's dictum concerning the presence of convex anterior and concave posterior branches in the three main veins R, M and Cu, our chief difficulty is really due to the fact that Rs in Plectoptera has become secondarily attached basally to MA, so that, in almost all fossil specimens, as well as in recent forms, no separate origin of Rs can be discovered. *But this is exactly what has happened in the Odonata also,* where the connection of MA with Rs is now almost universally accepted, and by nobody more definitely than by Martynov, who says (p. 263), referring to the Odonata: "Rs arises here from the base of M just as in mayflies and one certainly should look upon such a manner of origin as a secondary appearance, even if this tendency was acquired very long ago." The only point that Martynov seems to be in doubt about still is as to whether this vein is MA or MP; and that is why he continues to call it simply M. But the fact that it is a highly convex vein and stands next in order posteriorly to Rs should surely make it self-evident that he is dealing with MA.

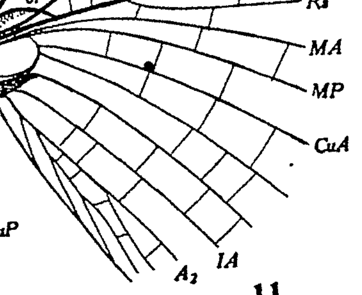
In the previous paragraph, I stated that "in *almost* all fossil specimens" no separate origin of Rs can be discovered. The word "almost" is used advisedly, for certainly, in some of the Kansas Permian wings, what is actually the true original base


Sc
R_1
R_2
IR_2
R_{3a}
IR_{3a}
R_{3b}
IR_{3b}
R_{4+5}
MA_1
IMA
MA_2
MP_1
IMP
MP_2
CuA
CuP
A_1
IA
A_2
A_3
A_4
3Ax
br
Sc
R_1
R_3
MA
MP

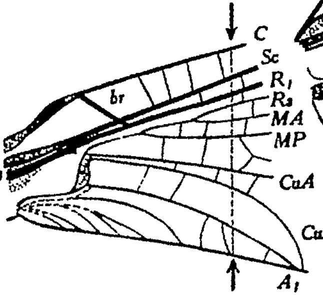
9


Sc
R_1
R_{2+3}
IR_3
R_{4+5}
MA_1
IMA
MA_2
MP
CuA
CuP
A_1
IA
A_2
A_3
A_4

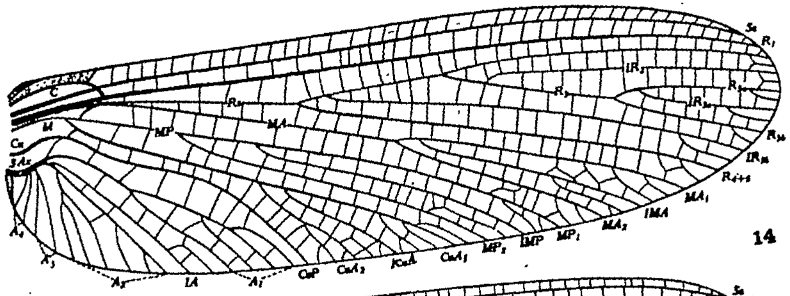
10


Sc
R_1
R_s
MA
MP
CuA
IA
A_2
br

11


C
Sc
R_1
R_s
MA
MP
CuA
CuP
A_1
br

12



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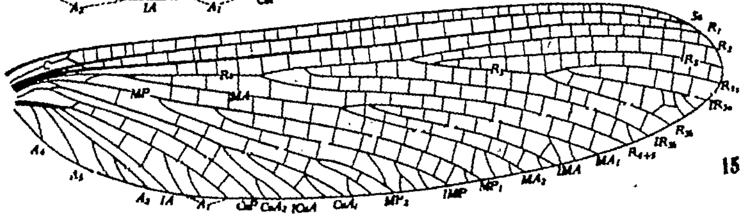

15

Tillyard—Kansas Permian Insects. Part 15.

of Rs is preserved, and the mode of fusion of Rs with MA can be studied. Figure 7 shows a specimen of *Protereisma* with this formation very clearly marked. Assuming that the upward arching of MA is primitive, which seems highly probable when we consider that this vein is more or less arched in all Palaeodictyoptera (though not in the Protephemeroidea), then it would appear inevitable that, as Rs regressed towards the base of the wing, the condition shown in Figure 7 must arise. This should be contrasted with the "stump-vein condition" shown in some specimens of the recent genus *Ameletus* (Fig. 12) where the primitive origin of Rs from R is marked by a stump-vein, though Rs and MA are now thoroughly well anastomosed basally, and their common stem is becoming obsolescent.

Now let us take any mayfly forewing, fossil or recent, and examine the alternating convex and concave veins radiating out from the base of the wing. We then at once observe the peculiar formations which I have already termed *triads* (1923), which are characteristic of all members of the order Plectoptera, fossil and recent. It is here necessary to distinguish clearly between the formation of the primary forks of R, M and Cu as explained by Lameere, and the secondary formations called triads which are developed more distally on these veins. A *triad* is essentially *a dichotomy of the vein concerned, plus an interpolated sector of opposite sign.* If the dividing vein is convex, the dichotomy is also convex, but the interpolated vein is concave; such a triad I have termed a *positive triad.* If the dividing vein is concave, then the dichotomy is concave but the interpolated vein convex; such a triad is termed a *negative triad.* But the primary forkings of R, M and Cu are *not* dichotomies of single veins, but *associations,* each consisting of a convex anterior vein joined basally to a concave posterior one. *Nobody knows yet how these have arisen;* for we have not yet discovered winged insects primitive enough to give us any clue to the problem. If, as I am inclined still to think, the mayflies are in many respects the most primitive, not alone of all living winged insects, but also of all known winged insects, both fossil and recent, then it is possible that something akin to the formation of triads may be the basic explanation of this ancient formation. In that case, the present association of the main veins in couples is actually not primitive but secondary, though admittedly extremely archaic. Anybody who studies carefully the connections between the main veins at the base of the wing of a fossil or recent mayfly must at any rate be impressed with a feeling that the association of MA with MP, and of CuA with CuP, is a secondary development, though that of R_1 with Rs would appear to be primary.

Now let us draw an oblique line across the wing, say, of *Ameletus* at such a level as to rule out of account all the triads, i.e. along the line of the arrows in Figure 12. Leaving out of account a set of smaller anal veins, which we shall deal with later, we count from the costa backwards a total of ***nine*** main veins, alternately convex and concave. These should be, according to my interpretation, C (+), Sc (—), R_1 (+), Rs (—), MA (+), MP (—), CuA (+), CuP (—), and A_1 (+), thus exactly agreeing with Lameere's theory. There appears to be no need to suspect that any main vein has disappeared or been eliminated. The only difficulties lie in the admittedly complex basal attachments of these veins; for, not only is Rs normally attached to MA, but the vein which I call CuA is frequently attached both to MP above and CuP below. However, just as we can parallel the attachment of Rs to MA by the similar condition in Odonata, so we can also parallel the double attachment of CuP by the condition in the more primitive types of Mecoptera, the double connection being what I have elsewhere called the *"cubito-median Y-vein."*

Let us now apply another test, by an examination of the anal veins. A good definition of the true anal veins is that supplied by Snodgrass (1927, p. 62) in the following words: "The *anals* are definitely attached to the third axillary or to an arm of the latter." The truth of this statement can be best seen in the wings of any of the Orthopteroid orders, e.g. the Perlaria. It should be contrasted with the fact that the cubitus "has no particular basal connections." An examination of either fore or hind wing of the more archaic groups of recent Plectoptera (e.g. *Tasmanophlebia,* Figs. 9, 10) must surely leave us in no doubt whatever as to the position of the third axillary and the veins which spring from it. The axillary itself is always a well-chitinized arch, more or less concave anteriorly and separated by a wide and deep hollow from the closely combined first and second axillaries to which Sc and R are attached. The vein that arises from the apex of the third axillary should be correctly 1A; we note that this is a convex vein, well developed in both wings, and running either sub-parallel to, or slightly diverging from, Cu_2. Next to this vein, posteriorly, is a concave vein, not so strongly developed, and, in the forewing, much shorter than 1A. Posterior to this again is another convex vein with irregular branches to the posterior margin of the wing; *all these branches are convex* and the wing-membrane on which they lie is convexly arched.

If now we compare this group of veins, arising from the third axillary, with the group of veins arising in the same manner in the forewings of the Orthopteroid orders, we note one important difference. In the Orthopteroid orders, the whole group consists of *convex veins* only. The vein named 2A, for instance, in the Perlaria, is equally as convex as is 1A, and so is its basal branch, called 3A by Comstock and Needham. In the fossil Protoperlaria, this convexity is equally marked, and the only difference is that the supposed 3A, in cases where it exists, is even more obviously a branch of 2A than in recent orms. It appears, therefore, certain that the concave anal vein of Plectoptera should not be named 2A at all, but should be considered as *an interpolated vein.* The best notation for this group of veins would be to use A_1 for the first anal vein, IA (not to be confused with 1A) for the concave interpolated vein, and A_2 for the following convex anal vein. Veins arising from the third avillary basad from A_2 may be termed axillaries, with the notation A_3, A_4.

If Martynov's division of all winged insects into Palaeoptera and Neoptera is correct, there should be no sign of any jugal lobe or vein corresponding with the *vena arcuata* or its branch the *vena cardinalis* in mayflies. But we may note how, in many recent forms, the projecting humeral angle of the hindwing passes under the strongly convex basal anal portion of the forewing, thus suggesting very strongly that the elements of a nealar region are already present in the mayfly wing, though not fully differentiated. Whereas, by contrast, this is not so in the Odonatoid orders, where only a single anal vein is present.

We have to take note, incidentally, of a peculiarity of the Permian fossil Plectoptera, viz. that, however beautifully the main portion of the wing may be preserved, the anal veins are seldom well preserved. The explanation of this appears to lie in a combination of two factors, viz. the extreme delicacy of both membrane and veins in the anal area, and the strong convex development of the third axillary. An examination of the anal area of the hind wing in any large Siphlonurid mayfly will show us these two characters present in marked degree, and there can be little doubt that the anal veins of the fossil wings were just as weakly formed as in these recent types. Further, during the process of fossilization, it may well be that, in many cases, the axillary cord did not become fully detached from the thorax; in which case part or whole of the anal veins would get torn away from the rest of the wing, as actually appears to have happened in many examples. Where the anal part of the wing is complete, the high ridge of the third axillary is seldom fully preserved, as it carries away when the rock is split open, just as the high ridge of R_1 does.

Our conclusion then, under this head, is that the mayfly wing differs from all other types of wing in that, while preserving the original first and second anal veins, there has also been developed an additional concave vein—the interpolated anal vein, IA—between them.

(2) *The Evidence from the Larval Tracheation:* Comstock and Needham (1899) and later Morgan (1912) were greatly puzzled by the marked incompleteness and variability of the tracheation in the larval or nymphal wings of mayflies. However, in examining the tracheation in larvae of primitive New Zealand genera of the family Siphlonuridae (1923) I did not find it by any means as variable as in the higher groups, and was able to make a number of deductions from my study of it. While I admit the uncertainty that attaches to this form of deduction, having been the first student of Odonata to attack Needham's method in that order, yet I think there is one deduction which may safely be drawn, and which nobody will attempt to controvert.

In his study of the basal tracheal supply of the developing wing, Chapman (in Comstock, 1918) has established the fact that there are two sources of supply, one entering the wing anteriorly and called the *costo-radial group*, and the other entering it posteriorly and called the *cubito-anal group*. From the former group the subcostal and radial tracheae are always derived; from the latter, the cubital and anal. The trachea of the media may arise from either group, or from a position somewhere between the two in forms in which the transverse basal loop is complete. *In no case does the cubital trachea arise from the costo-radial group.* If, however, we accept Martynov's and Handlirsch's interpretation of the venation of Plecoptera, this is exactly what must happen. To make this clear, it is only necessary to compare the tracheation of the forewing of the penultimate larval instar of *Ameletus* (Fig. 2) with the imaginal venation of the same insect or of *Tasmanophlebia* (Fig. 9), when it will be seen at once that the first cubitus must be the convex vein carrying the posterior pectinate series of branches, while the short, simple and strongly curved concave vein running below it must be CuP.

Having thus set forth my argument concerning the interpretation of the venation of recent and fossil mayflies, I propose to exhibit in tabular form the whole series of varying interpretations given to this complex venational system by different authors from Eaton onwards. The notation used in the present paper only differs in three respects from that given by me in 1926, viz. in the substitution of the notation "MP" for "M" for the posterior median vein, in the use of Lameere's notation CuA and CuP for the anterior convex and posterior concave cubital veins respectively, and in the revised treatment of the anal veins.

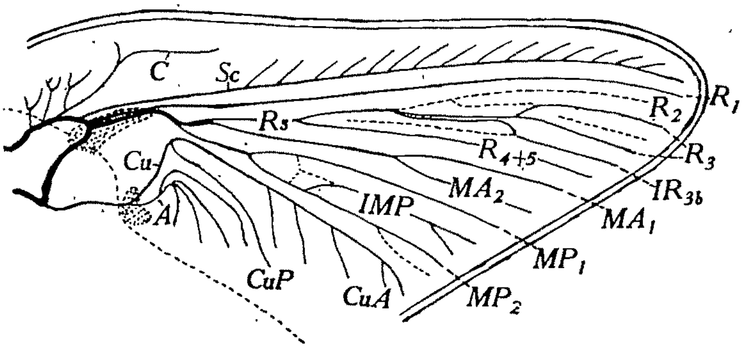

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Fig. 2. Tracheation of forewing of penultimate larval instar of *Ameletus ornatus* (Eaton). Order Plectoptera, Suborder Euplectoptera. Recent, New Zealand. From Tillyard (1923), with notation altered to agree with venational notation adopted in this paper. (See Table on p. 111.)

Entomologists of the Cornell school still continue to call the posterior concave cubital vein "1A", though it is in no sense a true anal vein, as its trachea always arises from the same main branch as that of the anterior convex cubitus. Dr. Bradley has recently written to me on this subject, and I gather that his main objection is to the use of the terms Cu$_{1a}$ and Cu$_{1b}$ for the branches of the distal fork of the anterior cubitus. These, he claims, should be called Cu$_1$ and Cu$_2$ by analogy with the distal branchings of Rs and M. I quite recognize the force of this argument, though I consider personally that the Cornell school sets far too much store by the constancy of the distal branches of the veins, as set out in Comstock's "hypothetical type." If

Dr. Bradley and his colleagues would recognize once and for all the very strong evidence that has been accumulated in favor of Lameere's view of the composition of the median and cubital veins, I am quite willing to change the terminology in favor of one that would be less objectionable to them. This can surely best be done by accepting Lameere's notation CuA and CuP for the two veins which I have hitherto called Cu_1 and Cu_2. It then follows at once that the distal branches of CuA will become CuA_1 and CuA_2, which, if I understand Dr. Bradley's position aright, should fully satisfy him and preserve the original intention of Comstock as far as the use of the suffixes is concerned. It also removes the use of the objectionable double suffixes attendant on such terms as Cu_{1a} and Cu_{1b}. These changes are adopted in the present paper, but I could never agree to the notation "1A" for the posterior concave cubital vein CuP; the only alternative would be to call it "Cu_3."

Table A sets out the comparative results of the different systems, the last column giving the notation used in the present paper.

THE CHAETOTAXY OF THE WINGS IN PLECTOPTERA.

It is usually stated that the wings in mayflies, as also in dragonflies, are entirely devoid of hairs of any kind. This is undoubtedly true of the imagines, but not of the subimagines. In the latter, two kinds of hairs are developed, viz. (1) the *marginal fringe,* and (2) the *microtrichia* of the membrane. In a large species of *Coloburiscus* from Australia, individual hairs in the marginal fringe have been measured by me up to as long as 110μ, though the average length is less than this. The marginal fringe is present in all subimaginal wings examined by me, and consists of extremely small, slender and closely-set hairs, very soft in texture. No trace of it can be seen in the imaginal wing.

The microtrichia in the subimaginal wing occur all over the membrane in the form of excessively fine, minute bristles of the order of 5μ in length in the same large species of *Coloburiscus* mentioned above, and considerably less in smaller species. They are very closely set together, the average distance apart being only about twice the length of the individual hair or a little longer. They appear to leave a slight impression in the imaginal wing, in the form of a minute granular mottling or irregularity of the surface.

TABLE A. Various Interpretations of the Wing-Venation of the Order Plectoptera.

(Note: + signifies *convex* veins, — *concave* veins.)

	Eaton, 1883		Comstock-Needham,	Morgan,	Martynov,	Tillyard,	Tillyard,	Tillyard, 1931		
Sign	Name	No.	1899	1912	1923	1923	1926	Notation	Name	Sign
+	Costa	1	C	C	C	C	C	C	Costa	+
—	Subcosta	2	Sc	Sc	Sc	Sc	Sc	Sc	Subcosta	—
+	Radius	3	R_1	R_1	R_1	R_1	R_1	R_1	Radius	+
—	Sector	4	Rs	M	RS	Rs (part)	Rs	Rs	Radial Sector	—
—		..	R_2	M_1	RS_1	$1R_{2a}$	R_2	R_2	Branches of Radial Sector	—
+	Branches of Sector	..	..	..	RS_2	$2R_{2a}$	IR_2	IR_2		+
—		..	..	..	RS_3	$3R_{2a}$	R_{3a}	R_{3a}		—
+		..	..	..	RS_3	$4R_{2a}$	IR_{3a}	IR_{3a}		+
—		/..	R_3	Rs	RS_3	$5R_{2a}$	R_{3b}	R_{3b}		—
+		4	R_4	Interpolated Vein 1	RS_4	R_{2b}	IR_{3b}	IR_{3b}		+
—	Cubitus Praebrachial	5	R_5	M_2	RS_5	R_3	R_{4+5}	R_{4+5}		—
+		6	M_1	M_3	MP	R_{4a}	MA_1	MA_1	Anterior Median	+
—		..	M_2	..	MP	R_{4b}	IMA	IMA		—
+		6	M_3	M_4	MP	R_5	MA_2	MA_2		+
—	Pobrachial	7	Cu_1	Cu_1	Cu_1	M_1	MP_1	MP_1	Posterior Median	—
+		..	..	Interpolated Vein 2	...	M_2	IMP	IMP		+
—		7	Cu_2	Cu_2	Cu_2	M_{3+4}	MP_2	MP_2		—
+	Anal	8	1A	1A	A_1	Cu_{1a}	Cu_{1a}	CuA_1	Anterior Cubitus	+
—		..	1A	1A	A_1	Cu_{1b}	ICu_1	ICuA		—
+		8	1A	1A	A_1	Cu_{1c}	Cu_{1b}	CuA_2		+
—	Axillaries	9_1	2A	2A	A_2	Cu_2	Cu_2	CuP	Posterior Cubitus	—
+		9_2	3A	3A	A_3	1A	1A	A_1	First Anal	+
—		9_3	3A	3A	A_3	2A	2A	IA	Interpolated Anal	—
+		9_2	3A	3A	A_3	3A	3A	A_2	Second Anal	+
+		..	..	..	...	...	...	A_3, A_4	Axillaries	+

The sockets of both the marginal fringe hairs and of the microtrichia are so exceedingly minute that it would be impossible to detect signs of either of them in even the best preserved fossil wing. Nevertheless, the fact that the subimaginal wing is definitely hairy, while the imaginal wing is not, suggests that ***hairlessness*** of the wing in Plectoptera must be a secondary character, and that it would be worth while searching for evidence of a definite chaetotaxy in the Permian fossil forms.

3

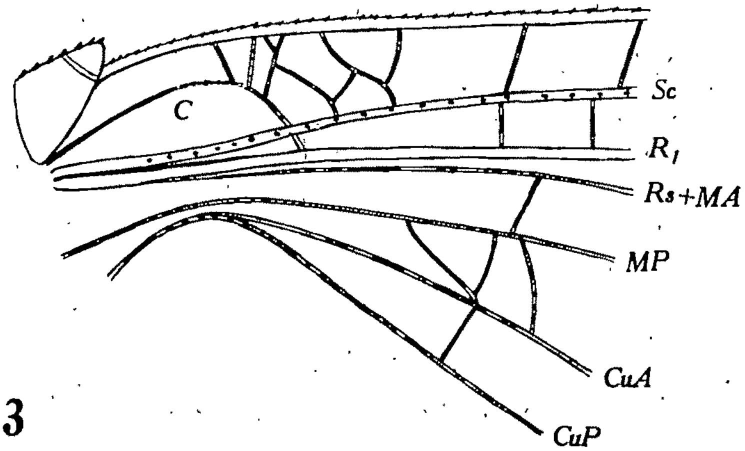

Fig. 3. Details from base of wing of Specimen No. 1118 (***Misthodotes ovalis,*** n. sp.) to show chaetotaxy of underside of wing. Obverse impression. (x 27.)

The results of my study indicate that certain types of hairs do exist in the Permian forms. The most conspicuous are developed ***only on the underside of certain concave veins,*** notably on Sc and CuP and sometimes on parts of Rs and MP (Figs. 3, 4).

The sockets of these hairs are placed far apart along the veins, and somewhat irregularly; each consists of a minute wart, darkly pigmented, fairly closely resembling those found on wings of many Planipennia. If a specimen consisting of obverse and reverse, both well preserved, be carefully examined, these dark sockets will be found on the veins mentioned, but ***only on the obverse impression.*** As I have already pointed out in dealing with the chaetotaxy of Protoperlarian wings (1928, p. 198), this means that the hairs in question must have been present only *on the underside of the veins.* As they are confined to the underside of the *concave veins,* their presence would appear to be connected in some way with the mode of folding the wings; since, in the position of rest in the mayflies, it is the *undersides* of the wings which are exposed, and consequently the projecting ridges of the concave veins which stand out most prominently. As these hairs are absent from the wings of all recent mayflies, in which the hindwings are greatly reduced, one may perhaps conjecture that the fossil forms with equal wings possessed also a certain amount of ability to raise and lower the wings pair by pair, in which case the hairs would be a protection against one pair rubbing against the other.

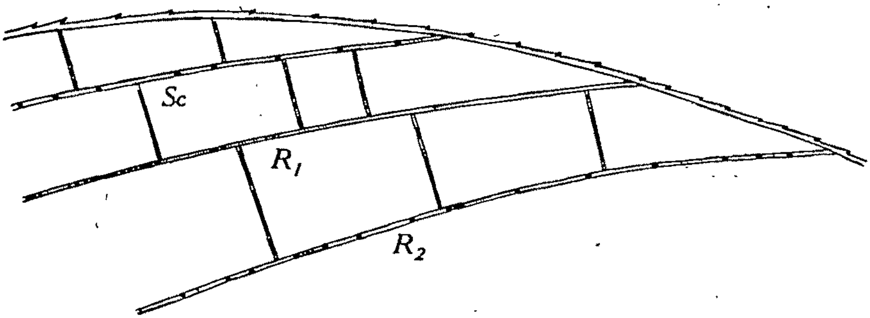

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Fig. 4. Detail from apex of wing of Specimen No. 1118 (*Misthodotes ovalis,* n. sp.): to show chaetotaxy of underside of wing. Obverse impression. (x 50.)

The *costal margin* of the wing, in almost all the fossil forms, is strongly serrated at the base, up to the end of the costal brace-vein. In some specimens, in the obverse impression, serration of the costal margin continues right to the apex of the wing (Fig. 4), while in the reverse impression only an occasional impression of the individual serrations can be seen. One concludes from this that the serrations were developed rather towards the underside of the costal margin.

In a number of specimens, it is possible to determine definitely that the small area of the wing lying between the basal portion of the costal margin and the costal brace-vein is not only very strongly chitinized but also armed with minute stiff hairs or small spines. It would appear highly probable that this area is homologous with the *precostal area* of the Protodonata, of a few true Odonata such as *Petalura,* and of the ancient Carboniferous type *Brodiea,* all of which show a similar type of structure, though without any development of a brace-vein. We should conclude from this that the common ancestor of mayflies and dragonflies possessed a true short costal vein, separated from the anterior margin of the wing by a small, heavily chitinized precostal area. The condition of the costal vein itself in the Permian mayflies would appear to be more primitive than that in the Protodonata or Odonata, since this vein does not lose its identity, but develops from its downward distal branch the famous brace-vein which has persisted in recent mayflies long after the main stem of the costal vein itself has disappeared.

DIFFERENCES BETWEEN SUBIMAGO AND IMAGO.

In living mayflies, the most marked difference between the subimago and the imago lies in the appearance of the wing-membrane. In the subimago, it is always dull and opaque, whereas in the imago it is brilliantly transparent, with all the main veins, and usually also the cross-veins, standing out very clearly against it. Further, subimagines often have the wings either entirely pigmented all over, or with a marked pattern, whereas in the imagines, coloration is usually confined to the costal and subcostal space, if present at all, or to brilliant translucent tinting of the membrane in brown or yellow.

Some of the fossil wings are deeply pigmented, either wholly or in part. While this does not necessarily indicate that the specimen is a subimago, it is usually possible to state definitely whether it is or not, by observing the impressions of the veins as contrasted with the membrane. If the veins stand out strongly in dark pigmentation, the specimen is probably an imaginal wing, in spite of its pigmented membrane. Otherwise, it should be classed as a subimaginal wing. With good impressions, it is generally not difficult to decide whether the fossil represents an imaginal or a subimaginal wing, provided that the worker already has wide familiarity with the appearance of mayflies in nature.

One very interesting point may here be mentioned. In the most specialized groups of mayflies, both subimaginal and imaginal life is very short. The most ancient of living types, however, such as some of the large New Zealand Siphlonuridae, are an exception to this rule. I have kept *Oniscigaster* alive in the subimaginal stage for close on four days, *Coloburiscus* for two and a half days, and *Ameletus* for two days. These forms will also live for several days in the imaginal stage. Thus it seems evident that the traditional short life of the mayfly must have been considerably longer in Lower Permian times. This is also borne out by the high percentage of Plectoptera fossilized in the Kansas beds; for the longer the individual subimagines and imagines lived, the better chance there would be of their being fossilized in the winged state.

Now, if one observes the surface of a pond or lake where mayflies are emerging in numbers, one will find that quite a number of them, through one cause or another, get drowned, and lie spread out on the surface of the water. I have been interested to examine the condition of such drowned mayflies. In the case of the subimagines, I have noted that a considerable number of them die with one or more of their wings longitudinally folded or crumpled. This also happens, but much more rarely, with the imagines. These observations have only been made with species of *Atalophlebia*, which are very common in Australia. In the case of large, strongly built species, it would appear probable that only the subimagines would have their wings longitudinally folded or crumpled, as the membrane is strong and stiff enough to keep the wing spread tautly out.

It is, therefore, of interest to find, amongst the fossils of this group, cases of longitudinal folding of the wings. The cases which I have studied appear to be almost all subimagines.

Apart from the condition of the wings, the tail-filaments offer conditions of marked difference between subimago and imago. Those of the subimago are the shorter, more weakly formed, and with the individual segments less differentiated. Not only do subimagines have weaker tail-filaments than imagines, but females have them weaker than males. In some extreme cases, the male imago have two extremely long and strongly formed cerci, without a sign of an appendix dorsalis, while the female subimago may have three equal and weakly formed tail-filaments, not half as long as those of the male. The common Australian *Atalophlebia costalis* Burm. is a good example of this. Consequently, in examining complete specimens of fossils, the condition of the cerci may assist in determining whether the specimen is a subimago or an imago, a male or a female.

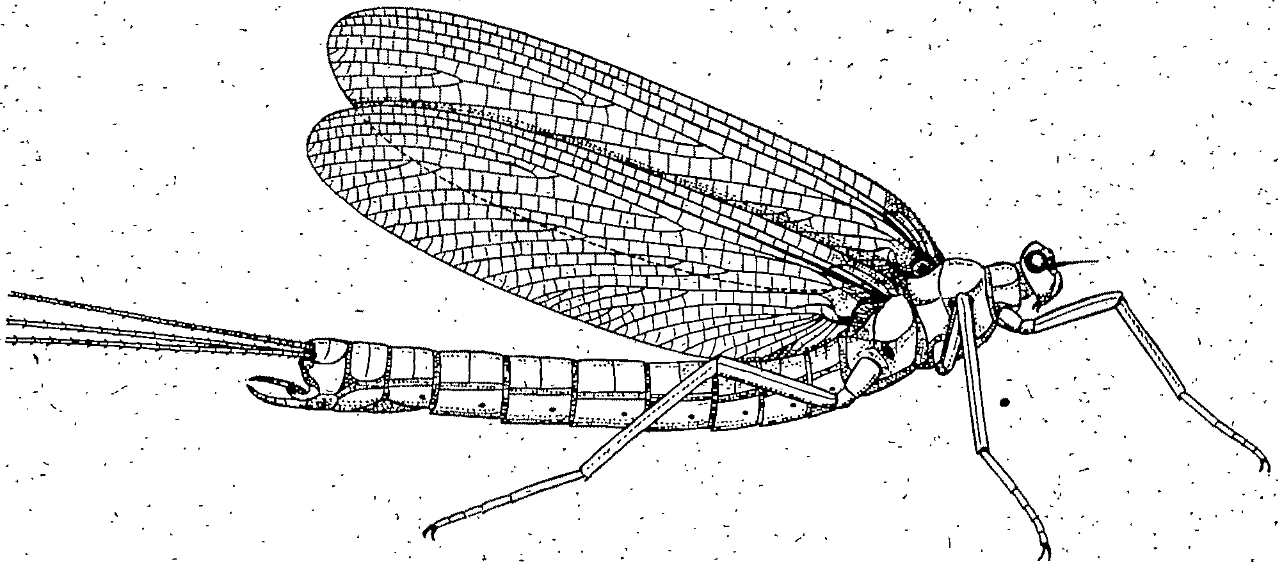

Fig. 5. *Protereisma permianum* Sellards. Order Plectoptera, Suborder Permoplectoptera. Lower Permian of Kansas. The complete insect restored in lateral view, as a type of the suborder. Restoration based chiefly on Specimen No. 5427. Actual length of forewing 19.7 mm.,

Order PLECTOPTERA.

Suborder PERMOPLECTOPTERA, n. suborder.

Mayflies of Permian age, in which the fore and hind wings were closely similar in shape, elongate sub-oval, and were not coupled together in flight. Head of moderate size, with eyes well separated. Prothorax of moderate size; meso- and metathorax large and subequal. Legs long and slender. Abdomen slender and more or less elongate in the males, somewhat shorter and stouter in the females; nine pairs of spiracles present on abdomen. Tail-filaments and male genitalia similar to those of recent forms. Two winged stages present, viz. subimago and imago.

General scheme of venation closely resembling that of the forewings of the more primitive groups of existing mayflies, e.g. the Siphlonuridae. Sc extending nearly the full length of the wing, parallel or subparallel to R_1. Rs arising near base, either by a slender stem from R_1 or, more usually, from MA by secondary fusion. Three sets of triads developed on Rs, the most distal triad being on R_3. A single triad developed on MA and another on MP. CuA either with or without a triad. CuP always a simple vein, more or less sigmoidally curved. Anal complex developed from a well-formed third axillary and consisting of true first and second anals, A_1 and A_2, both convex, with an interpolated concave vein IA, and in addition two or more basally situated axillaries.

Forewing generally slightly longer than hind and also slightly broader; but the forewing narrows posteriorly near the base much more than the hind, so that the anal veins of the latter are longer and better developed.

This suborder may be contrasted with the present-day mayflies or Euplectoptera, in which the hindwing is reduced or absent and is coupled in flight with the fore in the amplexiform manner. They may also be contrasted with Handlirsch's Upper Carboniferous order Protephemeroidea, containing the single genus *Triplosoba,* and more properly regarded as only a primitive suborder of the Plectoptera. These insects resembled the Permian fossils in general shape of wings and form of body, but differed from them in important points in the venation. The system of triads was less perfectly developed, there being only two sets on Rs and none at all on either MA or CuA.

One of the most important characters in which the Permian fossils appear to differ from recent forms is in the presence of a complete *costal brace.* This structure consists essentially of a short but distinct *costal vein* (Fig. 6, *C*) which forks at its distal end, sending an upward branch to the costal margin and a much more strongly formed downward branch across Sc to end in a strong fusion with R_1. The costal vein arises at the base of the wing, just above Sc, and runs for a distance of from 1.5 to 3.5 mm. before forking. This vein is definitely convex, and the downward strut or ***brace-vein*** lies at a higher level than Sc and crosses it from above before fusing with R_1. The space between costal margin and costal vein is always more or less heavily chitinized and appears to have been definitely coriaceous in some subimagines.

As will be seen later, some of the Permian forms have the costal brace more or less reduced. Hence, in spite of its interest and importance, it is advisable not to include this character in the definition of the suborder.

Another important character is to be found in the fact that the interpolated veins of all the triads are completely connected up basally. Whilst this appears to have been an invariable rule there is on the other hand great variability in the ***mode of connection*** of the interpolated veins (see below, p. 125). There is also considerable variability in the basal connections of the main veins. Rs is normally connected with MA only, but sometimes its original connection with R is preserved also. CuA is normally connected by a basal Y-vein to both MP above and CuP below, but sometimes one or other branch of the Y-vein is missing. These variations are discussed more fully below.

The condition of the mouth-parts is not known for certain; but it is reasonable to assume that they had already undergone a certain amount of reduction. One specimen shows what may have been a pair of reduced palpi. The eyes appear to have been well separated in both sexes. The antennae are not preserved, but it is reasonable to assume that they were very short.

The legs were long and slender; the coxae fairly well developed, the trochanters short, the femora and tibiae long and slender. There is no sign of the tarsus in any specimen.

Spiracles can be seen very clearly on the eighth abdominal segment in a well-preserved fragment (Specimen No. 5468), and on all the abdominal segments up to the eighth in Specimen No. 5427. They were situated latero-ventrally at about one-third of the length of each segment from its base.

The cerci and appendix dorsalis are preserved basally in a few specimens and were obviously well developed and closely resembling those of many recent forms. The collection does not contain any female specimen with the genital opening and its protecting plates present, but male specimens are present with the genitalia more or less completely preserved; the outstanding characters in these are the swollen forceps-basis, the long, jointed styli, and apparently also a strongly bifid penis. Figure 5 gives a restoration of *Protereisma permianum* Sell., based chiefly on Specimen No. 5427, and representing the type of the new suborder.

Before attempting to classify the large amount of material present into families, genera and species, I propose to make an examination of the details of the wing-venation, with a view to determining their variability and their possible use in a scheme of classification. For special reasons, the genus *Doter* Sellards is omitted from this analysis for the present, and will be dealt with in a subsequent paper. The venational study will be greatly helped by comparisons of the fossil venations with that of an existing archaic type of mayfly. For this purpose I shall select the Siphlonurid genus *Tasmanophlebia* Till. (Figs. 9, 10), since it is venationally one of the most archaic of known genera, and long series of it are available to me for study.

The principal characters to which the detailed study of structure and variation must be directed are the *costal brace,* the *origin of the radial sector,* the *basal connections of other main veins,* the *triadic system* and the *system of anal veins.*

(1) *The Structure of the Costal Brace.*

Figure 6, *A,* taken from *Specimen No. 5442,* shows one of the clearest costal braces in the whole collection. The costal border of the wing is arched at the level of the brace-vein and is also quite definitely serrated. The costal vein (C) arises just anterior to the base of the subcosta and runs parallel to the costal margin and nearer to it than to Sc for most of its length. It gives off anteriorly a series of veinlets to the costal margin. Distally, it bends downwards at the fourth veinlet and soon afterwards forks strongly. The anterior fork has the appearance of a strengthened veinlet and runs obliquely to the costal border. The posterior fork, forming the true *brace,* homologous with the *brace-vein* of the recent mayflies, runs obliquely downwards across and above the subcosta, to end in a strong fusion with the radius.

A slightly different form of costal brace is shown in Figure 6, *B*, drawn from a very large subimaginal specimen

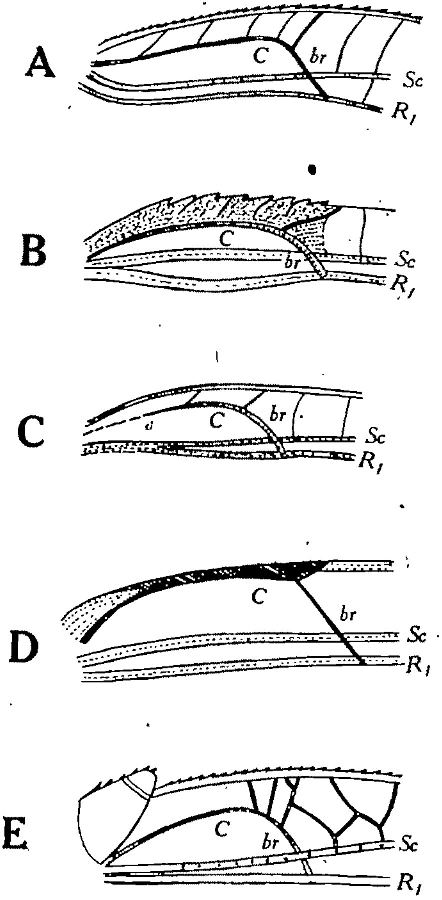

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Fig. 6. Types of costal brace-vein found in the suborder Permoplectoptera. A. From Specimen No. 5442 (x 11); B. From Specimen No. 1116 (x 11); C. From Specimen No. 5438 (x 16); D. From Specimen No. 5454 (x 16); E. From Specimen No. 1118 (x 21). A-D, views of upper surface of wing, family Protereismatidae; E, view of under surface of wing, family Misthodotidae, showing tegula-like process at base of costa. C, costal vein; br, brace.

(*No. 1116*) of the genus *Protereisma*. Here the general course of vein C and its branchings is much the same, but the whole area traversed, together with a short space beyond it, is very strongly chitinized. The area between costal border and costal vein is definitely coriaceous and armed with small setae. The costal margin is armed with strong, stout serrations, and the costal veinlets are slightly thickened ridges which end on the toothed margin. The chitinization of the costal vein itself is weaker basally than distally, and the actual brace is very stout and strongly chitinized.

A third form of costal brace is shown in Figure 6, *C,* taken from an imaginal specimen of *Protereisma* (*Specimen No. 5438*). The costal vein is weakly formed basally and arches up to run close below the costal margin. Only towards its distal end does it begin to give off veinlets to the costal margin, and then only one or two in number; distally it becomes much thicker and is darkly chitinized, ending in an oblique branch to the costal margin and a very strong downward brace to the radius.

The end-term of development of the costal brace in the *Protereisma*-series is shown in Figure 6, *D,* taken from *Specimen No. 5454,* where the costal vein makes actual contact with the costal margin for most of its length, diverging slightly distally from it, but with the whole narrow triangular space above it strongly chitinized. In this case, the brace-vein runs downwards practically across the whole width of the costal space to end, as usual, on the radius.

The above series of examples has been selected from the abundant material consisting of large to very large wings (15 to 30 mm. in length) and including the whole of Sellards' genera with the exception of *Doter* and *Misthodotes.* I shall speak of this series of wings as the *Protereisma*-series during the course of this analysis. Smaller wings of broader build and with well-rounded apices, and having usually a total length of only 10 to 12 mm., will be spoken of as the *Misthodotes*-series. As already mentioned, the genus *Doter* Sell., with delicate wings only about 7 mm. long, is not here taken into account.

Figure 6, *E,* shows a typical costal brace of the *Misthodotes*-series, taken from a subimaginal wing (*Specimen No. 1118*). Here we meet (in two specimens) with a curious structure in the form of a strongly chitinized triangular piece at the base of the costal region of the wing, and strongly suggestive of a *tegula.* The costal margin appears from near its outer angle as a delicately serrated border. The costal space is wide basally. The costal vein (C) arises from near the base of the tegula and is short and considerably arched; it is also very weakly chitinized for most of its length, only the actual brace portion being at all strongly marked. Three weak veinlets are given off distally to the costal border, the last of these corresponding with the upper branch of the fork in the *Protereisma*-series. Weak branched veinlets occur in the costal space distad from the base. In the obverse impression (i.e. on the *underside* of the actual wing) there is a row of stiff hairs or setae on the subcosta (Fig. 3).

We turn now to our comparison with living forms (Figs. 9-12) and note at once that the complete structure homologous with what has been described above is still present *in the hind-wing of Tasmanophlebia,* though reduced in size. The arched costal vein has become greatly thickened but the brace is still clearly defined; in spite of the close approach of Sc to R basally, its crossing over Sc and its final fusion with R are clearly seen. In the forewing of *Tasmanophlebia* (Fig. 9) the costal vein has made a complete fusion with the costal margin up to the beginning of the brace, and the margin up to this point is greatly thickened; the brace itself crosses the costal space at an angle of about 45 degrees and passes above Sc to end by fusion with R.

It will be seen at once, then, that present-day mayflies do actually possess the structure which is more perfectly preserved in the Permian forms, and that the strong brace-vein found in all recent forms can be strictly homologized with the downward branch of the costal brace in Protereismatidae. The nearest approach to the present-day formation in forewings is to be found in Figure 6, *D.*

One further point is worthy of note. In Figure 6, *B,* we noted that the whole area between the costal border and costal vein was strongly coriaceous. I suggest that the coriaceous border of Protodonata, of *Ditaxineura* amongst fossil Odonata, of the genus *Brodiea* in the Megasecoptera, and of Petaluridae amongst recent Odonata, arose in this manner, and may be rightly accepted as evidence in favor of an original costal vein having been present in the original ancestor of the Odonatoid orders.

(2) *The Origin of the Radial Sector.*

We have already noted, in our general discussion of Martynov's venational scheme, that one of the cruxes of the problem is the accurate determination of the origin and limits of Rs. It has been stated that, as a general rule in Plectoptera, the original base of Rs has atrophied and that vein has become *secondarily attached to MA.* In case there are still some who cannot accept the argument from comparative morphology, it seems advisable here to record the fact that the original condition of the origin of Rs occurs *not infrequently* both in the Permian fossil family Protereismatidae and also in such archaic recent genera as *Tasmanophlebia* and its allies. I have already recorded elsewhere, and again figure in this paper (Fig. 12; see also 1923, p. 152, Fig. 4) the occurrence of the *stump-vein condition* (*k*) in some forewings of the genus *Ameletus,* and had interpreted this as a definite indication of the position of the original basal piece of Rs. I now find a similar condition not uncommon in other archaic genera of Siphlonuridae, in the forewing. In the *hindwings* of *Tasmanophlebia,* however, I find several examples of what I take to be the actual original condition, with R arising *quite separately from* MA (Fig. 11). This formation has not been found in *both* hindwings of any single individual, but is not uncommon in one hindwing only of the two.

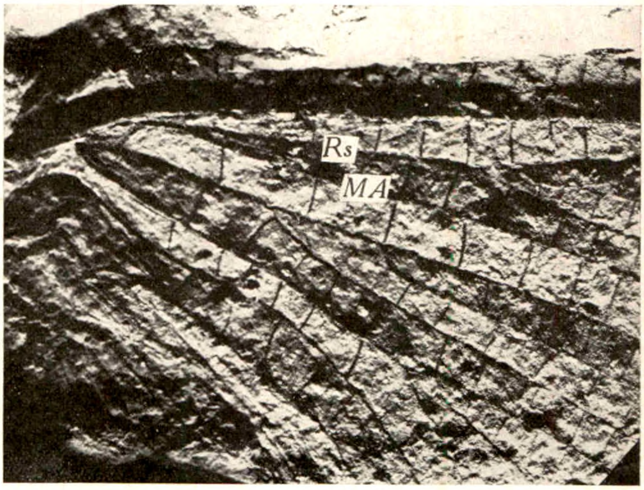

Fig. 7. Enlarged photograph of base of wing of Specimen No. 5452 (*Protereisma latum* Sellards) to show separate origins of Rs and MA (near top lefthand corner). (Photo by A. Tonnoir.)

For close comparison with this, I also show (Fig. 7) a condition which can be seen more or less clearly in several wings of the Protereismatidae, in which the separate origins of Rs and MA are distinctly shown, together with their subsequent anastomosis. The most striking point about this formation is the strong upward arching of MA, which must be adjudged to be the primary cause of the anastomosis taking place. The occasional formation in the hindwings of *Tasmanophlebia* is apparently a throw-back to a condition even more primitive than that exhibited in the fossils; yet we need not argue from this that *Tasmanophlebia* and its allies could not have been descended from such forms as the Protereismatidae, but simply that this character, like many others in the wings of this order, has not become completely fixed.

The great variability in the amount of anastomosis between Rs and MA in the fossil forms is another point to be noted. In some wings, these two veins part company at the level of the brace-vein, while in others the anastomosis may proceed to a point twice as far from the base of the wing as the end of the brace-vein on R. Measurements of these two points were made in twenty-one wings where the structures were well enough preserved to make such measurements worth while, and a selection of them is given here:

TABLE B.

No. of Specimen	Distance from base of C to end of brace on R	Distance from base of C to distal end of anastomosis
First series (Long braces):		
No. 1116	2.8 mm.	3.0 mm.
1119	2.8 mm.	3.0 mm.
5449	2.5 mm.	2.8 mm.
1103	2.5 mm.	2.5 mm.
5463	2.8 mm.	2.8 mm.
5465	3.5 mm.	3.5 mm.
Second series (Short braces):		
No. 5471	1.0 mm.	3.1 mm.
5435	1.5 mm.	3.0 mm.
5438	1.7 mm.	2.6 mm.
1118	1.7 mm.	3.4 mm.
5492	1.8 mm.	2.5 mm.
5470	1.2 mm.	1.8 mm.
5452	1.8 mm.	1.8 mm.

It should be noted that the actual amount of anastomosis between veins Rs and MA varies greatly; usually this amount cannot be actually measured, since the exact point of origin of Rs is lost. In those cases where this origin is preserved, as in Figure 7, the length of the actual anastomosis is found to be actually less than a millimetre.

I am not able to allow any generic or specific value to the character of the basal formation of Rs and MA or to the extent of the anastomosis between them. The most we can say is that one would naturally expect the narrowest wings to show the greatest amount of anastomosis; but even that wide statement does not fully hold.

(3) *Variations in Basal Connections of the Main Veins.*

There is even more variation in the basal connections of M and Cu than there is in the origin of Rs. Figure 18 shows what I take to be the most primitive condition, in which we can take note of three things, viz. the free, distinct basal stalk of the media, the similar but more curved stalk of the cubitus, and the Y-vein connection of CuA, the upper arm of the Y joining it to M a little basad from the point of upward origin of MA, and the lower arm joining it to CuP. On Lameere's theory, this lower arm should be the most primitive, being exactly comparable with the upwardly arching portion of MA from the stem of M, while the upper arm should be merely a specialized cross-vein developed into a strong strut, viz. the same piece that I have elsewhere called M_5 in the Panorpoid orders. But it is equally admissible to believe that the convex vein CuA was originally developed as an interpolated vein between the concave veins MP and CuP, and so was originally connected up basally with both of them, though the tracheal connection in the larval wing usually (but not always) links CuA and CuP to a single trunk and thus gives the basis for the similarity of naming.

In most of the fossil wings in which the base is preserved, it is the connection of CuA with CuP which either degrades to the form of a cross-vein, or disappears altogether. Very seldom indeed does the converse condition appear, but it may be seen in Figure 22, a wing of the *Misthodotes*-series.

In wings of recent mayflies, the original basal stem of Cu is degraded and changed into a sort of semi-chitinized arch which curves upwards concavely to the base of the wing to join the stem of M above it. In most forms the connection of CuA is also lost, this vein becoming secondarily attached to M; but in *Tasmanophlebia* (Fig. 9) the connection is retained in both wings; this is also true of a number of other genera of the Siphlonuridae.

Again, I am not able definitely to assign generic value to any of the above variable characters, though it seems that, within rather wide limits, they may help to define certain species in so far as the tendency and direction of variation differ in different species and according to the narrowness of the wing.

(4) *The Variations in the Triadic System.*

It is of very great importance to a correct understanding of the classification of mayflies that we should fully grasp the structure and development of the system of triads which is so characteristic of the order Plectoptera as a whole. It is, of course, a truism that Nature never retraces her steps; but this statement appears to have hindered some authors from accepting the theory that the middle members of triads are *interpolated veins*. Their argument runs thus: In the fossils we find all the supposedly interpolated veins joined up to one or other branch of a main vein; in all the more highly evolved mayflies of the present day, these connections are not present; therefore the interpolated condition is secondary, not primary.

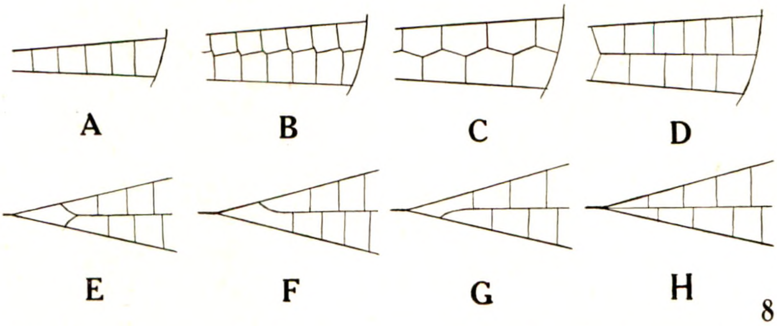

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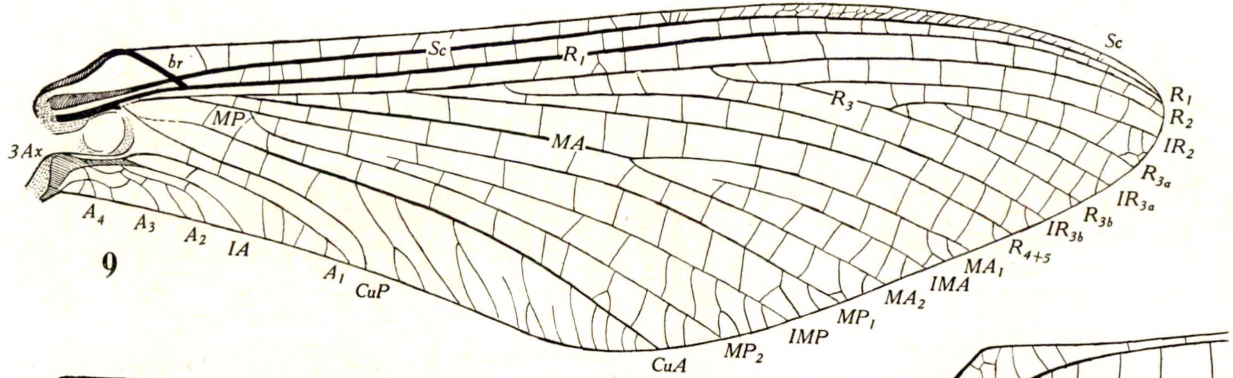
Fig. 8. Diagrams showing the formation of triads. A, Single cell-row. B, Linked series. C, Zig-zag vein (Odonata). D, Interpolated straight vein. E, Holotriad. F, Protriad. G, Metatriad. H, Mesotriad.

This argument fails through lack of understanding as to how interpolated veins originally arose. The track whereby the complete middle vein of a triad degrades to a disconnected interpolated vein is actually not quite the same as that whereby

Nature originally formed the triad. It is the Odonata and the closely related Protodonata that provide this key; from them we can learn that the origin of the middle veins of triads is to be found in the evolution of the typical cross-vein system of Odonatoids and Plectoptera. In these orders, the cross-veins are normally at right-angles to main veins. When a space between two branches of a main vein widens, a single row of cross-veins (Fig. 8, *A*) becomes replaced first of all by a linked series (Fig. 8, *B*). The next step is the alignment of the cross-pieces. If, as in Odonata, upper and lower cross-veins are arranged alternately at wide and fairly equal intervals, then the newly-formed intermediate vein will be zig-zagged (Fig. 8, *C*) as in the interpolated branches of the radial sector of most Zygoptera, and it may be a very long time before this zig-zagging is straightened out. If, however, as is usual in Plectoptera, the cross-veins are nearly or quite opposite one another, or too weak to exert the necessary pull on the cross-pieces, then a straight vein will be formed much more quickly, as in Figure 8, *D*. The first or most basal of the upper and lower cross-veins thus become the Y-vein connection of the fully formed interpolated vein.

If both are well developed, the type of triad formed may be called a *holotriad,* i.e. a triad with complete Y-vein connection of the interpolated vein to both upper and lower main veins of the set (Fig. 8, *E*). If the upper connection only is developed, the triad may be termed a *protriad* (Fig. 8, *F*); if the lower only, the triad is a *metatriad* (Fig. 8, *G*). Very rarely the interpolated vein runs right into the angle of the branching veins on either side of it; such a formation may be called a *mesotriad* (Fig. 8, *H*). Besides these types, there is also, of course, great variability in the distance of the basal connections of the interpolated vein from the fork.

Now if we examine the triads in the forewing of the archaic existing genus *Tasmanophlebia* Till. (Fig. 9), we are struck by the fact that all the interpolated veins of the radial sector are complete, and only those of the two median triads are incomplete. A similar condition occurs sometimes in *Siphlonurus,* and rarely in *Oniscigaster.* In Figure 9, the first or basal triad of Rs is a protriad, the second is a metatriad and the third or most distal one (on R_3) a protriad. An examination of a long series of specimens of this genus shows very great


br
Sc
R1
Sc
R1
R2
IR2
R3a
IR3a
R3b
IR3b
R4+5
MA1
IMA
MA2
MP1
IMP
MP2
CuA
R3
MP
MA
3Ax
A4
A3
A2
IA
A1
CuP

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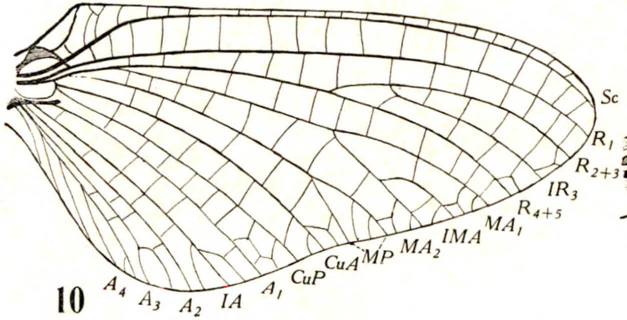
Sc
R1
R2+3
IR3
R4+5
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MA2
MP
CuA
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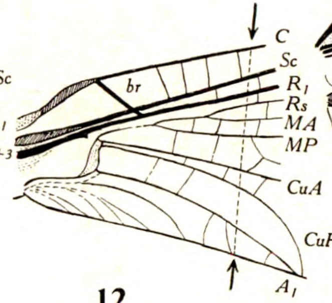
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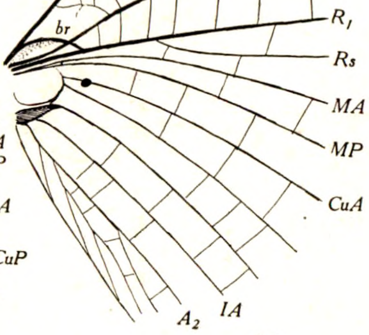
Sc
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Rs
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MP
CuA
br
A2
IA

11

variability in the condition of these triads. In nearly sixty wings examined in this genus, all types of triads were found, the mesotriad being, as might be expected, the rarest condition. Besides the four conditions already defined, there were a number of cases of double-linkage, i.e. either a pro- or metatriad with two oblique connections to its proper vein. In the case of the vein IR_{3b}, several wings showed incipient degradation of the interpolated vein, the basal end just failing to connect and lying free for a very short space in the fork of the triad. The great majority of the basal triads were protriads, and this was also true of the distal triads on R_3. In the case of the middle triad, the great majority proved to be metatriads.

One need only compare the condition found in the radial sector of the archaic genus *Tasmanophlebia* and its allies to become convinced that they have retained the complete interpolated veins of the triads as shown in all the Permian fossil types, and hence that the incomplete triad typical of most recent mayfly wings is a secondary development.

In the hindwings of *Tasmanophlebia* (Fig. 10), all the triads are complete, though variable, and the same holds good for a number of Siphlonurid genera. But *Tasmanophlebia* is the only type known to me in which some indication of the original shape of this wing is preserved, and it is noteworthy that the length of the hindwing in the species figured is actually *more than one-half that of the forewing.*

Let us now examine the condition of the triads in the Permian fossils. We have already stated that all the triads are complete. The Yale Collection contains thirty-nine complete or nearly complete wings in which the details are sufficiently well preserved to make an analysis of the triads worth while. The following table gives the results (the term "1st Rs" indicates the most basal triad of Rs; "2d Rs" indicates the middle triad; and "3d Rs" indicates the distal triad situated on R_3):

Fig. 9. Forewing of *Tasmanophlebia* sp., Mount Kosciusko, Australia. Suborder Euplectoptera, Family Siphlonuridae, with venational notation adopted in this paper. (See Table on p. 111.) *3Ax,* third axillary; *br,* brace.

Fig. 10. Normal hindwing of same species.

Fig. 11. Base of abnormal hindwing of same species (reversion to ancestral type) showing separate origins of Rs and MA. Cf. Fig. 7.

Fig. 12. Base of forewing of *Ameletus ornatus* (Eaton), New Zealand. Family Siphlonuridae. To show stump-vein formation at *k,* indicating original point of departure of Rs from R. The line between the two arrows passes across all the main veins before the origins of any triads (see p. 128).

TABLE C.

Analysis of types of triads in Protereismatidae.

Type of Triad	Name of Triad											
	1st Rs		2d Rs		3d Rs		MA		MP		Cu$_1$	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Protriad ……	35	89.7	2	5.4	24	92.3	35	84.2	30	88.3	23	100.0
Mesotriad ….	0	0.0	0	0.0	0	0.0	2	10.5	0	0.0	0	0.0
Metatriad ….	3	7.7	33	89.2	2	7.7	0	0.0	1	2.9	0	0.0
Holotriad ….	1	2.6	2	5.4	0	0.0	1	5.3	3	8.8	0	0.0
Total ……	39	100.0	37	100.0	26	100.0	38	100.0	34	100.0	23	100.0

It will be seen that the result of the above analysis is surprisingly like that found for the recent genus *Tasmanophlebia,* viz. the most basal and distal triads of Rs are both predominantly *protriads,* while the middle triad of Rs is predominantly a *metatriad.*

We shall indicate later on how greatly Sellards relied on triadic characters to found his genera and species; not only making use of the actual type of triad present in a given wing, but also the comparative positions of origin of triads on given veins, i.e. how far along the vein from base or apex they arise. The above analysis will serve to show, I trust, that no reliance can be placed on the type of triad, either for generic or specific characters. As regards the second, I believe it to be almost equally unreliable. An analysis of the same thirty-nine wings of Protereismatidae as before gives the following results:

The basal triad of Rs arises at a point from only one-fourth to as much as two-fifths of the distance along the free Rs, measured from its origin from the anastomosis with MA up to its distal end on R_2. The commonest condition is at about one-third.

The middle triad of Rs arises at a point from as little as one-fifth up to as much as almost one-half (three-sevenths) of the distance along R_2, measured from the origin of the first triad to the distal end of R_2. The commonest position in the *Protereisma*-series is about one-third; in the *Misthodotes*-series it is somewhat more distally situated

The distal triad of Rs arises at a point from about two-fifths to about three-fifths along R_3, measured from the origin of the middle triad to the distal end of R_3. This triad is, on the average, more distally placed in the *Protereisma*-series than in the *Misthodotes*-series, the average in the former being a little more than one-half, in the latter somewhat less.

It follows that, in the *Misthodotes*-series, the two more distal triads of Rs are approximated somewhat, thus tending to form a single *pentad;* whereas in the *Protereisma*-series the three triads of Rs are approximately evenly spaced.

The condition seen in the *Misthodotes*-series is closely analogous to that found in *Tasmanophlebia* forewings (Fig. 9). In the latter, however, secondary bendings of the branches of the middle triad, and sometimes also of the distal one, often more or less mask the original structure of the separate triads, so that the correct naming of the interpolated veins can only be discovered by reference to the Permian fossils.

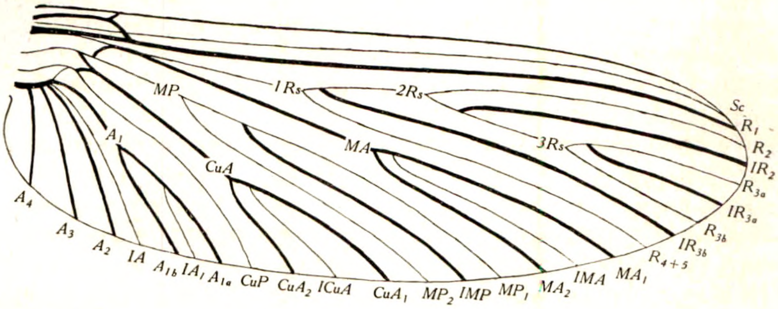

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Fig. 13. Diagram of main veins in wing of *Protereisma* to show arrangement of the system of triads. Thickened veins are convex, thin veins concave. Venational notation as adopted in this paper. (See Table on p. 111.) *1Rs, 2Rs, 3Rs,* the three triads of Rs.

The triad of MA in the Permian fossils is always placed at a level distad from that of the basal triad of Rs, i.e. from one-third to as much as three-fifths of the distance along the free length of the vein, the average being about one-half. The triad of MP, on the other hand, is always placed at a level basad from that of the basal triad of Rs, i.e. from as little as one-eighth up to not quite one-half at the most. It is, on the average, much closer to the base in the *Protereisma*-series than in the *Misthodotes*-series, and it is only in the latter group that a position from one-third to almost half-way from the base is found.

The vein CuA shows greater variability in form than any other vein in the wing. In the *Misthodotes*-series, no true triad is developed, and the vein runs almost straight or with a slight curve to the posterior margin of the wing; at the most, terminal twiglets are to be seen. In the *Protereisma*-series, however, there is always a well-developed triad, and frequently the original three branches of the triad have other shorter veins interpolated between them, as shown in Figure 14. The triad may arise as near to the origin of the vein as two-fifths, or up to as much as three-fifths, the more distal positions being the commoner.

Neither of the above conditions comes very close to that found in forewings of the Siphlonuridae, where CuA has developed a pectinate series of descending branches (Fig. 9). This is a specialized condition which could conceivably have been evolved from either type present in the fossils. If, however, we look at the hindwing of recent mayflies (Fig. 10) we find that CuA is always a simple vein (except, perhaps, in the richly-veined and aberrant genus *Campsurus*). Further, the modes of branching of this vein in the forewings of other recent families is highly variable, and the most anterior branch in every case continues the basal portion of the vein without a break. One must conclude, therefore, that recent mayflies have been evolved from a type resembling the *Misthodotes*-series, in so far as the vein CuA must have had no triad.

The presence or absence of a triad on CuA appears to me to be one of the most important characters for classification in the fossils, and will be made use of in this paper.

Figure 13 represents diagrammatically the triadic system in the family Protereismatidae, all the triads being normally *protriads* except only the middle triad of Rs, which is normally a *metatriad.*

(5) *The System of Anal Veins.*

The outstanding feature about the anal area of the Permian fossil mayflies is that, even in otherwise practically perfect wings, it is either not preserved at all, or, if preserved, the veins are very faintly impressed upon the rock. I have already suggested reasons why these conditions might be expected to occur, if the anal area in the fossil wings were anything like that of those of recent forms and particularly of the hind wings. It remains now for us to try to determine the venational plan of the anal area of the fossils, and to compare this with the same area in recent wings.

The best preserved anal area in the collection appears to be that of one of the *Misthodotes*-series (Fig. 20) in which the rounded basal angle of the wing can be faintly made out and all the anal veins appear to be present. The specimen most probably represents a hind wing. The distal part of the third axillary can be clearly seen, with all the anal veins radiating from it. From the apex of the axillary a connecting vein runs backward and slightly upwards to join the curved basal part of Cu. The rather narrow space enclosed by the third axillary, the basal piece of Cu and this connecting vein would appear to be homologous with the much wider, glassy area separating anals from cubitus in recent mayflies (Figs. 9, 12). The condition in recent hindwings is somewhat closer to that of the fossils than in the forewings, as the space is not quite so wide and the connecting vein appears to be still intact and fully chitinized.

From the distal end of the axillary, the vein A_1 runs obliquely outwards and downwards, its distal branch being subparallel to CuP. A_1, however, forms a positive triad, of which the primary fork arises very close to the apex of the axillary. Basad from the posterior branch of this triad one notices a weak concave vein which connects up separately with the third axillary basally; this must be the vein IA or the *interpolated anal* already spoken of on p. 107. Just basad from this on the axillary arises the true convex vein A_2, whose distal branch runs fairly close to IA; this vein has a series of branches on its basal posterior side. Basad of this there appear to be two weakly formed descending veins without any branches, each of which arises separately from the axillary. These *axillary veins,* here termed A_3 and A_4, appear to be closely similar to the most basally situated descending veins in the anal area of the hindwing of recent Siphlonuridae.

In the *Protereisma*-series, several wings have the vein A_1 preserved, and in every case it is a branched vein, convex, and either forming a simple triad arising not very far from the base, or with some extra distal branches such as have been noted already in the case of CuA. In a few wings also the connecting vein running to Cu can be made out. In my original drawings of the wings of *Protereisma* (1923, Figs. 1a, 3) I showed the vein situated basad to A_1 as *convex* and considered it a branch of A_2. However, on further study, this vein appears to me now to have been definitely *concave,* and therefore homologous with IA. It appears to have been connected basally sometimes with the convex vein A_2 proper, sometimes with the axillary as in the *Misthodotes*-series. No triad appears to be present on A_2 in the forewings; in the hind the mode of branching was evidently variable. The forewing would appear to have had two short basal veins or axillaries just basad from A_2 and the hindwing either two or more similar veins.

On the whole, then, the anal system in the fossils agrees fairly closely with that of the recent forms, but more closely resembles that of hindwings rather than of fore. In recent forms, it is clear that the anal area of the forewing, already narrower in the fossil forms than that of the hind, has undergone further compression, whereas the same area in the hindwings has obviously undergone further expansion from an original condition wider than in the fore. For both wings, the fossils provide a type which lies in the direct ancestral line of recent forms.

Having now reviewed the principal venational characters of the suborder, I propose to divide it into two families as follows:

Large wings, length 16 mm. up to 30 mm. or more, comparatively narrow (ratio of length to breadth being greater than 3 to 1). CuA with a well-developed triad ....Family PROTEREISMATIDAE Sell.

Moderate-sized wings, length 9 to 12 mm., rarely 15 mm., comparatively broad (ratio of length to breadth 3 to 1 or less). CuA either a simple vein or only with short terminal twiglets ....Family MISTHODOTIDAE, n. fam.

(*To be concluded.*)

CONCERNING RILLENSTEINE.

J. D. LAUDERMILK AND A. O. WOODFORD.

Pieces of limestone bearing a grooved or channelled pattern of distinctive form have been called *Rillensteine* by German geologists. The rilled rocks may range in size from small, loose pebbles to large masses of limestone (or gypsum) occurring in place as exposed outcrops. This form of rock sculpturing has been reported as occurring in various parts of the world, chiefly in arid regions. It has been considered by some observers to be the result of solution, and by others to be due to wind erosion.

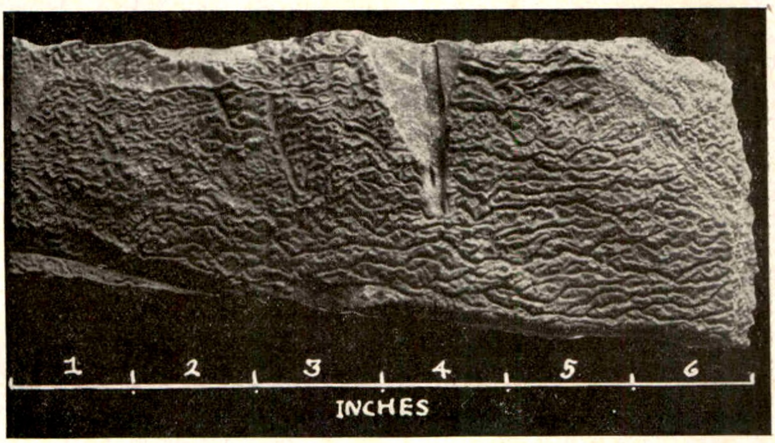

Fig. 1. Rills of the First Type. Adelanto, California.

The rills here considered are small, commonly a millimeter or less in diameter. They are usually round-bottomed, and are not widened cracks. They are not to be confused with coarser surface details, such as cavernous solution effects on the one hand, or on the other the broad, parallel grooves and sharp intervening ridges which commonly bear indisputable evidences of wind erosion.

CLASSIFICATION OF THE RILLS.

Rillensteine may be classified as follows: *First Type,* rills unpolished, more or less parallel, anastomosing but only moderately sinuous, and usually rather shallow (Fig. 1); *Second*

Type, rills unpolished, rough, in streamlike systems and very sinuous, usually deep, sometimes with sharply crested ridges and more or less complete transverse septa (Fig. 2); *Third Type,* rills rough and running in various directions, no single direction being dominant (Fig. 3); *Fourth Type,* rills shallow, smooth, frosted, and showing any of the patterns of the first

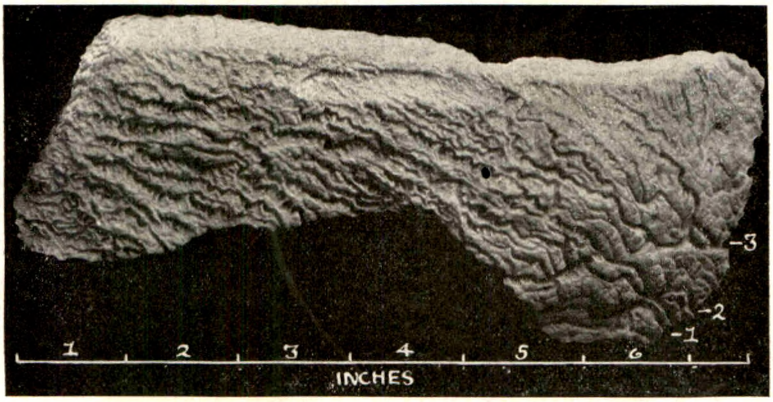

Fig. 2. Rills of the Second Type. Garnet Hill, California.

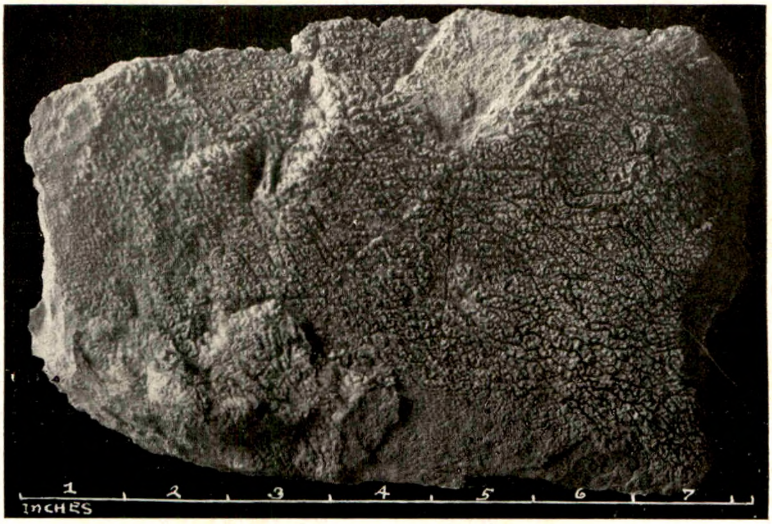

Fig. 3. Rills of the Third Type. Adelanto, California.

three types (Fig. 4). The third type, when deeply cut, grades into cavernous weathering. In all these types the rills vary in size from almost microscopic pittings or elongated depressions

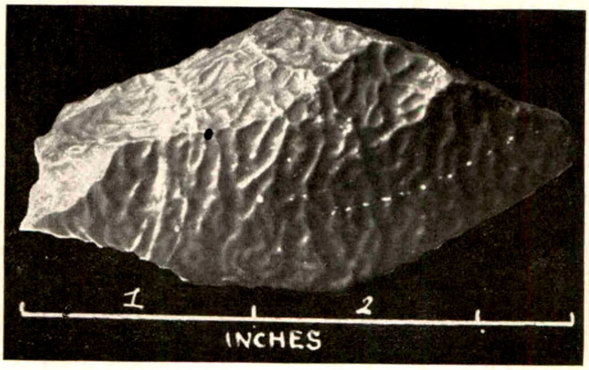

Fig. 4. Rills of the Fourth Type. Salt Creek, Death Valley, California.

to channels having a diameter of three or four millimeters. In the deeper rills of the first three types the sides of the channels are frequently undercut. The walls of the deeper

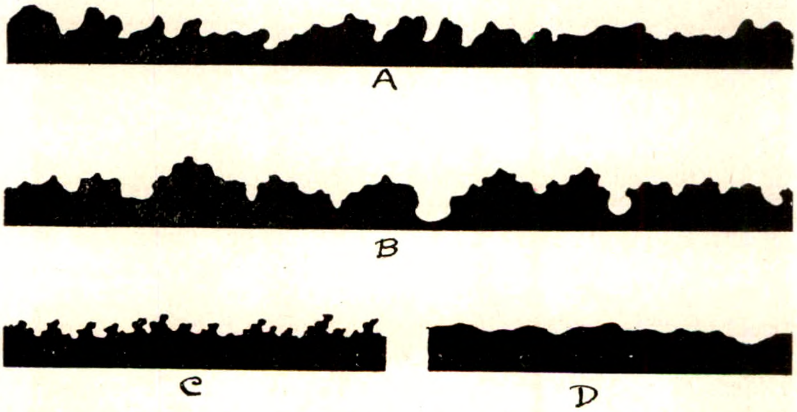

Fig. 5. Rills in transverse sections. A, First Type; B, Second Type; C, Third Type; D, Fourth Type.

channels commonly show in relief some suggestion of the crystalline structure of the limestone, with minute cleavage cracks, or incised crystal boundaries, or both. Transverse sections of rills of all four types are shown in Fig. 5.

SELECTIVE SUMMARY OF PREVIOUS WORK

The earliest mention of rilled limestone which has come to our attention is that of G. K. Gilbert (1875, p. 83 and plate 9). He saw numerous effects of wind erosion on a mesa near the Colorado River, below the mouth of the Virgin River. He considered that, as one result of the work of the wind, "limestones are carved, with a network of vermicular grooves, into the most beautiful arabesque designs."

Rilled limestone was discovered anew in North Africa by J. Walther (1891, p. 438 and pl. 4, fig. 2). Walther showed that the *"mäandrische Furchung"* of the rock surface in at least one case was present only on the lee side of a block, the windward side of which had been intensely eroded by wind. He considered the smooth, meandering grooves of the lee side to be the result of wind erosion by the spent sand blast.

Andreae (1897, p. 34) proposed the term *"Rillensteine"* which commonly, but not always, has been reserved for the designation of the meander-rilled limestones here considered.

Abel (1901) studied a very few small, flat, radially rilled sandstone pebbles from the Sahara, whose grooves extended rather uniformly around the peripheries. He suggested that desert winds toss small pebbles about with such violence that features are developed similar to the fusion grooves of meteorites.

Foureau (1903, p. 217), among others, considered the rills (*vermiculations*) on Saharan limestones to be the result of wind erosion. Haug (1907, pp. 394-395 and pl. 50, figs. 2, 3, 5) accepted this explanation and copied some of Foureau's figures, showing rills of our fourth type.

In his *Gesetz der Wüstenbildung* Walther (1924, 4th ed., pp. 163-164) revised his conclusions in the light of further observations by himself and others. He says that the rills occur on angular as well as rounded stones and cover not only small pebbles, but also heavy blocks a foot across. Where the *Rillensteine* lie on a clayey desert soil, there the rills are sharp and resemble etch-figures made by weak acids. Calcite cleavage cracks which run through the rock are eaten out more deeply, and form sharp grooves 1-4 mm. wide at the surface. But where sand is strewn over the surface, or where *Windkanter* indicate previous sand blast action, there the *Rillensteine* are glazed, their patterns are vague, and on the windward side the rills gradually disappear. By digging one may find sharply grooved *Rillensteine* in the desert soil, but only down to 10-20 cm. depth. On fist-size pieces Walther saw continuous rills which were rough where soil covered, but above the soil were glazed, rounded, and finally worn away. An illustration shows such a pebble from Thebes. The conclusion follows that the rills are channels formed near the surface by the etching effect of the rising, concentrated desert soil solutions. As the clay soil is blown away, the limestone blocks are exposed and the rills first smoothed and polished and finally obliterated.

Salomon (1910, p. 307) very briefly mentioned "beautiful wind-sculptured stones" observed in Spitzbergen, with ripplings like those of desert stones.

B. G. Escher (1913) found in the Tödi region of Switzerland that the weathering of dolomite results in sharp, angular cracks and shallow pits with patterns somewhat similar to those of some desert *Rillensteine.* These were ascribed to solution by surface waters.

Kessler (1913) described and figured Spitzbergen limestone *Rillensteine* which closely approximate the typical desert patterns (our first and fourth types). He pointed out that on Spitzbergen the soils are always either wet or frozen, and hence the winds, though high, have no tools. He accepted the Escher explanation, as Walther's theory of concentrated, rising solutions does not apply in Spitzbergen.

Steinmann (1913) in a discussion suggested that the rare, but torrential, downpours of the South American deserts result in the etching of limestone surfaces by solution, giving *Rillensteine.* The effect is from above down, and the dissolved calcium carbonate is often again deposited beneath the surface stones.

Hobbs (1917, pl. 23b) figured a wind-grooved limestone fragment from the Libyan Desert, which shows finer, superimposed rills, apparently of our first type. These are considered by him to be the work of the wind, merely smaller rufflings superimposed upon the larger (Hobbs, 1917, p. 40).

Salomon (1916) gave an excellent review of the *Rillensteine* literature and now ascribed the Spitzbergen ripplings on limestone to solution. This change of view was a result of observation at Portofino, Italy, of limestone pebbles in conglomerate, etched by sea spray in the manner of Spitzbergen and Tödi! However, Salomon concluded that even though some desert *Rillensteine* originate as solution grooves, the polished types are the result of wind rippling. Solution grooves may be entirely inorganic, or due to algae, lichens, roots of higher plants, insect larvae, etc. Thus similar effects are produced in a number of ways.

Blanckenhorn (1916 and 1921, pp. 179-180) pointed out that in Egypt limestones and other rocks are eroded, rather rarely, by the wind in straight, parallel furrows, with broad rounded bottoms, and separated by narrow, sharp ridges. The much commoner rills (*Mäanderfurchen*) found only on limestone, are smaller, narrower grooves which on the upper sides of the blocks resemble stream systems with the sources at the highest parts of the blocks. These rills were, therefore, considered the work of dew or raindrops which coursed downward, dissolving as they went. The whole upper side of a buried block, sheltered from the wind, may be surrounded by a raised margin, suggesting the amount of solution which has taken place. The rills on the lower sides are independent of those above and they were considered to be the work of rising solutions.

Kumm (1922) attacked Walther's idea of deep etching by rising solutions on the general grounds of our knowledge of the soil solution and its behavior during surface evaporation. He did suggest the possibility of such etching if acid waters, perhaps from the weathering of pyrite, fill drying cracks in the postulated clay soil, but he favored an extension of Blanckenhorn's dew hypothesis to explain all *Rillensteine*.

Hume (1925, pp. 211-212) reported rills on limestone outcrops in protected places, where wind erosion cannot take place. One of his figures (Fig. 203) is close to our second type. Hume quoted Walther's second (1924, 4th ed.) explanation with approval.

Palache (1926, pp. 138-139) described and figured the Sierra Sandon iron meteorite, a coarse octahedrite from the Chilean desert. The upper surface of this meteorite shows clearly defined, reticulated rills of our third or fourth type, which in places bring out the octahedral structure. The lower surface, which was embedded in the sand, is free from the markings, but is coated with a thick layer of rust. Palache ascribed the markings to the action of wind-driven sand. He also noted fine bands of limonite following the octahedral structure, perhaps the result of the alteration of troilite.

Bourcart (1928, p. 49), apparently writing without knowledge of the German work on the subject, figured a half dozen fine examples of rilled limestone from the Sahara and ascribed the *vermiculations* on limestone to wind erosion. No particular argument was presented. He pointed out that the grooves commonly run more or less parallel to the prevailing wind direction, but sometimes radiate from a center. He figured a single "schist," which shows rills of our fourth type. Another figure shows a smooth, uneroded fossil bone projecting from a rilled limestone surface.

Blackwelder (1929) has studied rilled limestone, especially in Death Valley. He concluded that "Solution, even in the desert, causes pitted and fretted surfaces on limestones, and such markings have been ascribed to wind abrasion."

Bryan (1929) has recognized the solution-facetting of limestone pebbles partially buried in the soil of semi-arid localities in the western United States. Rough surfaces are formed which are somewhat similar to those of *Rillensteine.*

In recent textbooks, Passarge (1924, p. 689) ascribed the *"Wurmrillen"* on limestone to wind erosion, whereas Schaffer (1922, pp. 200-201) accepted Walther's second (1924, 4th ed.) explanation. It is apparent that no unanimity of opinion has been reached.

OBSERVATIONS IN SOUTHERN CALIFORNIA.

We have studied rilled limestones at four localities near the western margins of the Mohave and Colorado Deserts of Southern California and rilled gypsum in the Kettleman Hills, Kings County, California. We have examined also a few samples from other places in California and Texas. All the California localities lie in Russell's Mojave or Colorado types of Hot Deserts, BWh or BWhh (Russell 1926, map). The Texas locality is called Hot Steppe (BShw) by Russell (1931, map).

Garnet Hill occurrence. Garnet Hill is located at the northwest angle of the Colorado Desert in Riverside County, California, just east of Garnet station (formerly Palm Springs station) on the Southern Pacific railroad. It is an isolated hill near the east end of San Gorgonio Pass, rising to an elevation of 900 feet, 200 feet above its surroundings. The average annual precipitation is about four inches.[1] The sides of the hill are rather thickly covered with typical desert vegetation, in which the creosote bush (*Larrea divaricata* Cav.) is prominent. The hill is an outcrop of a very coarse, unconsolidated breccia. Tertiary marine fossils can be found. There are numerous boulders of granitic and gneissic rocks, and less abundant blocks of quartzite, basalt and limestone.

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[1] U. S. Department of Agriculture, Weather Bureau, Climatological Data, California section. Average precipitation for Indio for the years 1920 to 1930 inclusive.

From its exposed situation the hill is subject to frequent and sometimes violent sand storms, as a result of which many of the rocks show the broad grooves separated by sharp ridges, and the pinnacles and deep pits characteristic of erosion by wind-blown sand. Some quartzite pebbles have become polished *Windkanter,* and nearly all boulders show some evidence of wind sculpturing.

ANALYSIS I. Caliche, Garnet Hill, California. Analyst, J. D. Laudermilk. Average of close duplicates.

Insoluble (quartz, biotite, clay minerals, etc.)	20.6%
SiO_2 (acid soluble)	0.5
Al_2O_3	0.6
Fe_2O_3	0.7
CaO	40.0
MgO	1.8
CO_2 (Ca and Mg equivalent)	(33.3)
H_2O	1.3
organic	2.2
alkalies	trace
Li	trace
P_2O_5	trace
SO_3	none
nitrates	none
Total (if all Ca and Mg as carbonates)	(101.0)%

Solution as well as wind erosion is going on here. Indirect evidence for solution of calcium-bearing minerals is given by the abundance of caliche in the soil. Some of the samples collected were embedded in this substance. The accompanying analysis of the caliche (analysis I) indicates a somewhat sandy but otherwise rather pure calcium carbonate, with a small quantity of soluble silicates and a trace of phosphate, but free from salts of other acids. The water in this analysis and in those which follow represents the total moisture. The determination was made according to Penfield's method (Hillebrand, 1919, pp. 77-79). All operations were carried out in glass or porcelain.

Rillensteine were observed as loose limestone fragments and as large embedded masses of limestone with rills on the exposed surfaces. Rills of our four types occur at this locality, though the fourth type does not show quite the typical low relief.

One of the samples studied in detail was taken from a mass of white dolomitic limestone several feet in diameter, which had all the exposed surfaces heavily rilled (our third type). The rock contains numerous fine flakes of graphite which project from the crystalline mass of the limestone into the channels. The edges of the graphite flakes were examined microscopically and found to be sharp and well defined with no evidence of having been eroded by the wind. To all appearances the calcite had been removed by solution leaving the graphite intact and partly embedded. Sharply defined dolomite granules project into the channels of the rills, suggesting that the dolomite has resisted solution more than the calcite. Under the microscope it is seen that the rock is a very pure, crystalline limestone, with large crystals 2 or 3 mm. across, in a tangled groundmass of smaller crystals, down to 0.1 mm. in width. This rock was analysed chemically, with the results shown in Analysis II.

ANALYSIS II. White Dolomitic Limestone, Garnet Hill, California. Analyst, J. D. Laudermilk. Average of close duplicates.

Insoluble (largely graphite)	0.4%
Fe_2O_3 Al_2O_3	1.1
CaO	50.6
MgO	4.6
H_2O	0.3
CO_2 (Ca and Mg equivalent)	(44.7)
Total (if all Ca and Mg as carbonates)	(101.7)%

Neither microscopic study nor chemical analysis shows any minerals which might have been the sources of acid solutions.

Adelanto Occurrence. This occurrence of *Rillensteine* is located in the Mojave Desert about 10 miles northeast of the town of Adelanto, California. The rilled rock is dark gray limestone which occurs as an extensive outcrop along the crest of a low hill. The hill is sparsely covered with vegetation in which creosote bush and an unidentified grass or grasslike bush may be said to predominate. The giant yuccas or Joshua trees (*Yucca brevifolia* Engelm.) which are a striking feature of the landscape, indicate by their slanting position a prevailing wind from the northeast. There is much drifted sand at this locality and in some instances the sand partially overlies the rilled rocks. The average annual precipitation at Llano, not far from this locality, was about six and one-half inches for the three years 1918-19 to 1920-21 (Thompson, 1929, p. 80).

Despite the abundance of drifted sand there is surprisingly little evidence of eolian rock sculpturing of the types found at Garnet. Nearly all the limestone boulders and pebbles which lie thickly strewn about show well-defined rills. The evidence for solution is pronounced at this locality, caliche being abundant both about the foot of the outcropping rock masses and in the seams of the rocks.

As a general condition on rock surfaces having an approximately horizontal position the rills are oriented with the wind. On vertical or nearly vertical rocks, the rills are vertical unless the rock is exposed to the wind. In such cases the rills are horizontal. In some cases it was observed that a rock having horizontal rills on one face has vertical or nearly vertical rills on another.

At the crest of the ridge the rock is split and fissured. Almost all the surface shows the rills, which are as abundant near the top as they are lower down. Frequently the rills show evidence of having a relation to the vertical direction of the fissures. Analysis III shows the composition of dark gray limestone from the summit outcrop. Although the caliche gives evidence of the action of solution at this point, there is no possible source of acid except from the atmosphere itself.

ANALYSIS III. Dark Gray Limestone, near Adelanto, California. Analyst, J. D. Laudermilk. Average of close duplicates.

Insol. (Muscovite, quartz, etc.)	10.6%
Fe_2O_3 Al_2O_3	0.8
CaO	48.6
MgO	1.8
H_2O	0.4
CO_2 (Ca and Mg equivalent)	(40.1)
Total (if all Ca and Mg as carbonates)	(102.3)%

Water was poured upon a rock surface in place at this locality, in order to discover its movement relative to the rills. A rock was chosen having a slope of thirty-five degrees and bearing horizontal rills oriented with the prevailing wind. This rock had numerous cracks and grooves which were crossed by the rills at right angles. Water was poured on the rock at the highest point and the rapid runoff was in the direction of the cracks and grooves, but the film of moisture which remained followed the direction of the rills, this apparently being due to capillary action.

An Adelanto limestone surface having deep rills of our third type was studied in the laboratory under a magnification of fifteen diameters. The bottoms of many rills, while appearing polished to the unaided eye, showed a white, granular deposit occurring in the interstices between the crystals of calcite composing the rock. In some instances the white deposit, which was later proved to be $CaCO_3$, occurred on the surfaces of the crystals. A jet of air directed on the rock while it was under examination removed the deposit, exposing a fresh surface beneath. A 2 mm. seam of rather porous travertine, practically pure calcite, divided the surface of the rock at one place. The rills, while continuous on both sides of the seam, had not channelled through it, the seam being raised above the levels of the beds of the channels to a height as great and in some cases greater than the ridges separating adjacent channels.

Black Mountain Occurrence. Black Mountain is situated on the Mojave Desert, in California, about fifteen miles northeast of Victorville, and a half mile west of the Sidewinder Mine. It has an elevation of about 800 feet above its surroundings, and is broken into numerous ridges and clift masses, between which the wind often sweeps with considerable violence. The average annual rainfall is probably close to that of Barstow, twenty miles away, where the 1907-1920 average was 4.29 inches (Thompson, 1929, p. 86). The slopes are well covered with typical California desert vegetation and the rocks of the cliffs and ridges are in nearly all cases covered with various types of xerophytic lichens such as *Parmelia* and *Collema.* No sand was found at this locality and no definite evidence of wind erosion.

The outcropping rock on Black Mountain is a somewhat metamorphosed breccia made up of fossiliferous or massive limestone fragments, most of which are only a few centimeters long, embedded in a non-fossiliferous, occasionally slaty, matrix. The matrix usually consists of calcite, with perhaps 20% of clastic quartz grains, but sometimes it is silicious and very fine-grained, with new-formed clinozoisite (?) in some cases and muscovite or talc in others. The fossils are thought to be Carboniferous.

Many of the rock surfaces show abundant evidence of disintegration due to solution and atmospheric weathering. They are leached, spongy, bleached, locally iron-stained, grooved along the lines of rhombohedral cleavage, and with caliche in crevices and on the surface. Abundant white and brown travertine suggests spring deposits. Much chalcedony and limonite also occur, the latter rarely as cubes pseudomorphic after pyrite. Not uncommonly the breccia matrix is colored a dark brown by a thin coating of ferruginous matter, but the limestone blocks are usually free from stain. Qualitative analysis of the rock and of the products of its decay failed to show the presence of any acidic oxides excepting SiO_2, CO_2 and SO_3, the last-named being found in only a few cases.

Many limestone blocks on all parts of the mountain are rilled. In many cases the cementing material, which shows no rills, stands up above the embedded rilled limestone blocks. A peculiar type of channelling, sometimes seen in other occurrences but common at Black Mountain, consists of a deep V-shaped groove completely surrounding a breccia block, the slope of one side of the groove being composed of the block and the other being composed of the embedding material. Also, the rills were observed to channel around fossil corals which extend outward from the rock mass to an approximate distance of five or six millimeters. Neither fossils nor matrix show evidence of wind erosion, and either may be coated with a superficial deposit of iron oxide.

At *Carrizo (or Coyote) Mountain,* 25 miles due west of El Centro, California, at the west edge of the Colorado Desert, some of the large oysters in the Tertiary sediments bear fine rills of our third type, though no good examples of rills were found by us on the crystalline limestone of the underlying basement complex. The rainfall here may be slightly greater than at Garnet.

Rillensteine in great variety and perfection occur at several places in Death Valley, California. We are indebted to Professor Eliot Blackwelder of Stanford University for the following statement concerning the abundant pebbles of our fourth type, occurring near McLean Spring, northwest of Furnace Creek:

"Some of the crooked grooves which Ekblaw[1] and I have ascribed to solution, are limited to one or two sides of the pebbles. On the other side, which was more exposed to the sandblast, they have probably been erased. It seems to me possible that these stones preserve a record of climatic changes,—the rilled surface being made in somewhat moister epochs and the sandblast facets being made in the dryer and perhaps windier times intervening."

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[1] Dr. George E. Ekblaw. Ill. State Geol. Survey.

RILLED GYPSUM.

Dr. R. D. Reed has furnished us samples of pure, massive, fine-grained gypsum (Fig. 6) collected by himself and by Mr. Paul Teas from outcrops about a mile east of Sweetwater, Texas. This gypsum bears shallow but well-defined rills of our first and fourth types, the former type merging into the latter by imperceptible gradations. A granular, obscurely crystalline deposit of gypsum closely resembling caliche in appearance coats portions of some of the samples. This perhaps represents a redeposition of the gypsum removed in the formation of the rills.

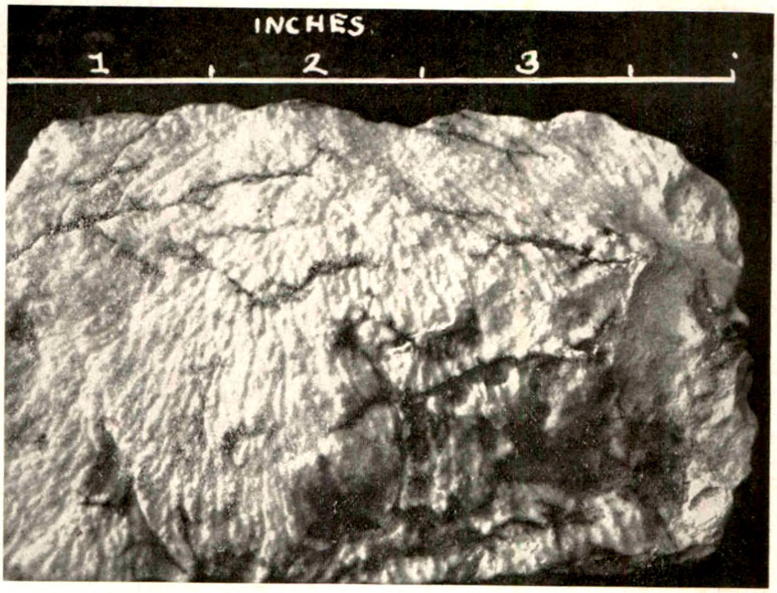


Fig. 6. Rilled Gypsum. Sweetwater, Texas.

Similar and deeper rills on a coarse-grained, but clayey, gypsum have been shown us by Dr. Ralph Stewart of the U. S. Geological Survey at the west side of the Middle Dome in Kettleman Hills, Kings County, California.

So far as our observations go, large crystals of pure gypsum show regular, geometric solution patterns, but no *Wurmrillen.*

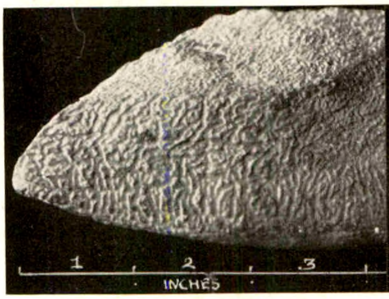
GROOVES CAUSED BY ORGANISMS.

Müller (1897) found limestone blocks on the shores of Alpine lakes with pits and short grooves suggestive of an Alpine landscape or the work of boring mussels, but in fact occupied by calcareous algae and apparently formed by them. Müller's illustrations (1897, p. 28) do not closely resemble any of the *Rillensteine* here considered. However, Professor Loye Miller has told us orally that on California deserts *Rillensteine* sometimes bear algae or lichens.

Dunn (1911, pls. 62 and 63) has figured several kinds of lichens growing on pebbles. None of the radial or other types of colonies have patterns closely resembling those of *Rillensteine.*

EXPERIMENTAL OBSERVATIONS.

Smooth limestone surfaces were treated with very dilute acid solutions, and both rilled and unrilled surfaces were subjected to silt and sand blasts.



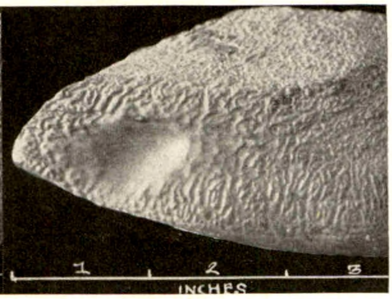


Fig. 7a. *Rillenstein* from Garnet Hill, before sand blasting.
Fig. 7b. *Rillenstein* from Garnet Hill, after sand blasting.

Experiment 1. A sample of gray crystalline limestone (Fig. 7a) having well-defined rills, in several of which mica flakes were present, was exposed to the action of a silt blast for 32 hours. Fine sandy silt was used as the cutting agent. The mechanical analysis of this silt is as follows:

65.0%	less than 1/16 mm. diameter, mostly near upper limit
28.3	11/16-1/8 mm.
4.2	1/8-1/4 mm.
2.4	1/4-1/2 mm.
99.9%	

At the end of the operation a slight superficial polishing of the rilled surface, with a loosening of the mica flakes, was observed.

The same experiment was tried with a specimen of rilled white limestone which carried partly embedded graphite flakes. The graphite was polished and rounded off by the silt blast.

Experiment 2. The first specimen of Experiment 1 was next exposed to the action of falling grains from a spent sand blast. Quartz-feldspar sand with the following size analysis was used:

1/2 to 1 mm. diameter	1.1%
1/4 to 1/2 mm. diameter	73.2
1/8 to 1/4 mm. diameter	25.6
less than 1/8 mm. diameter	0.1
	100.0%

The blast was allowed to act for 32 hours. A very slight superficial polishing resulted.

Experiment 3. The rock used in Experiment 2 was next exposed to the full action of the blast for 12 hours, using the same sand as in the previous experiment. The part of the slightly oscillating block which received the full brunt of the blast had the rills nearly obliterated. The resulting polished surface closely resembled that found on certain samples of *Rillensteine* of our fourth type from Death Valley and northern Africa.

The rock was finally exposed to the action of the blast for 35 hours more, making a total of 47 hours. The center of impact of the blast varied by about a centimeter, due in part to constant oscillation of the block. Over the area of maximum impact the ridges between the rills were completely destroyed, and away from this area they were more or less smoothed out or rounded off (Fig. 7b).

In this experiment the sand blast did not produce new rills, the whole effect being that of first smoothing and then obliterating previously existing markings.

Experiment 4. A rilled limestone block was next ground and polished to a perfectly flat surface, the rills being entirely ground away. A very dilute HCl solution was prepared (1 cc. of concentrated acid to the liter), and allowed to drop from a series of twelve glass tubes, drawn down to small openings and fitted with cotton wicks which nearly but not quite touched the upper edge of the smooth limestone surface. The face of the block was in a nearly vertical position and subjected to the action of the acid for a period of 76 hours. At the end of this time the general surface was reduced by solution of as much as ¼ inch of limestone, and in addition deep rills of our first type were formed, as shown in Fig. 8. The rills were in some cases undercut and polished (but not frosted).

Experiment 5. A modification of the above experiment was next tried, the rock used being a slab of highly polished gray and white variegated marble. In this case the acid solution was caused to flow in a thin film without the points of local concentration which existed in Experiment 4. At the end of 80 hours numerous more or less parallel rills resembling those shown in Fig. 8 were produced.

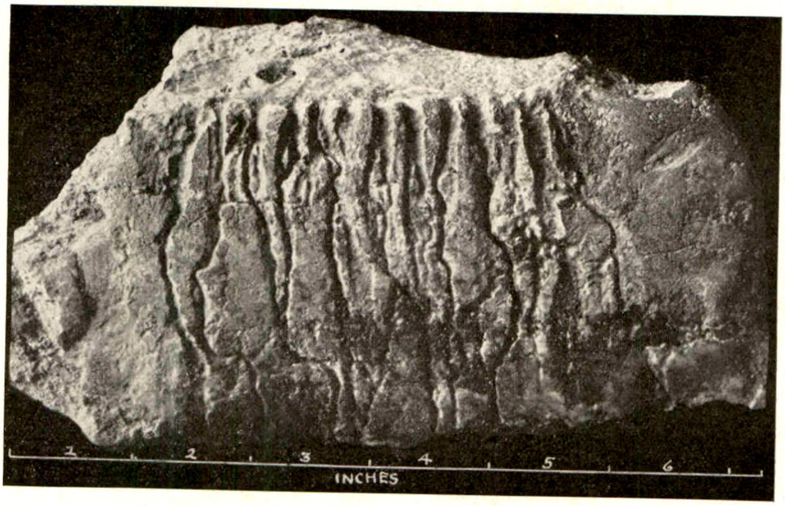


Fig. 8. Limestone from Adelanto, California, showing artificial rills.

Experiment 6. A pale yellowish gray limestone spall from our first mentioned locality (Garnet, California) shows deep, anastomosing rills of our second type. The rills at the margin, designated 1, 2, 3 in Fig. 2, are very deeply cut and about 3 mm. wide at the widest point. The rills are partly undercut as shown by their transverse sections in Fig. 5. In many cases the rills are strongly recurved in remarkable ox-bow forms. Some of these channels have transverse septa which block their courses. In other cases channels running parallel have had their separating walls perforated with minute holes.

Water was dropped on the surface of this rock at its highest point as it lay practically flat on a horizontal surface. In the first trial a relatively large volume was used; the water filled the channels and overflowed, streaming down the rock on all sides without following the channels. The rock was then dried in the oven, and water dropped on it slowly. The water followed and quickly filled most of the channels. Channels with septa filled more slowly, the water apparently passing over the septa by capillarity.

SUMMARY AND CONCLUSIONS.

1. The little rills have been observed on hundreds of limestone and gypsum pebbles and outcrops. They have also been reported on schist by Bourcart (1928), on sandstone by Abel (1901), and on a desert meteorite by Palache (1926). Kessler (1913, p. 414) mentions hematite, but gives no details. Abel's rills are unusual in pattern, and Bourcart's description does not exclude the possibility of a very high content of calcite or dolomite.

We have only found the rills on dense, massive limestone or gypsum. Where, as at Adelanto, rilled blocks are cut by veins of more porous calcite, the veins do not show the rills.

2. *Rillensteine* are very common in the African and American deserts. A very few good examples have been found elsewhere, notably in Spitzbergen (Kessler, 1913).

Rarity of liquid water seems an essential condition. Even in the semi-arid portions of the San Bernardino Mountains, California, where the pine forest runs out into juniper and chaparral, the limestone country rock is roughened by solution effects which go far beyond the rills here considered.

3. Often the rills more or less exactly parallel both the wind direction and larger grooves demonstrably due to wind erosion. This may be due either to an eolian origin or to wind control of the movement of water films.

4. Commonly *Rillensteine* are embedded in or associated with caliche or travertine. This has been almost invariably true of the cases studied by us, and Steinmann (1913) emphasizes the same point. Commonly local solution is indicated as a necessary preliminary to deposition of the caliche.

5. *Rillensteine* occur in many situations, loose on the desert, as small blocks in soil, and also as great, bare ridges of outcropping limestone. Walther (1924, 4th ed.) has empha-

sized the second case, and has shown that a partially buried block may bear continuous rills which are rough where soil covered, but smooth and rounded where exposed. This was explained by Walther as indicating the formation of sharp rills beneath a soil cover, and subsequent smoothing of exposed surfaces by the wind. But the procedure may be slightly more complicated. Sharp rills may first be formed in the open, and part or all later covered by a protective coating of soil. Finally the wind may remove the soil and smooth the rills.

6. Crystals of mica and graphite, if present in the rock, project into the rills without modification of form.

7. We do not see any close similarity between any one of our four types of rills and the various patterns of algal or lichen colonies known to us. We have seen no evidence that organisms are in any way connected with the origin of *Rillensteine,* but we are unable to exclude this possibility.

8. Our experiments have shown (1) that a silt or sand blast does not produce rills on smooth limestone, but on the contrary gradually smooths out a rilled surface; (2) that rills similar to the deeper and sharper of the natural types can be formed by slow application of dilute acid solutions; and (3) that the mica and graphite crystals projecting into natural rills are rounded off and more or less completely removed by a silt or sand blast.

We conclude from the facts just enumerated that the rills almost certainly are produced by solution, the work of the occasional rainstorms of an arid region. In many cases the carbonic acid in the rainwater must suffice, as no other source of acid seems available. The films of water course down firm limestone surfaces, or are driven along them by the wind. Rills, started in the same haphazard fashion as larger stream ways, will be accentuated later, especially by the last drainage from a rainstorm. Nevertheless, every desert cloudburst will cover the whole rock surface with a thick film of water, and may slightly change and add to the rill pattern. It is apparent on inspection that cleavage and other cracks sometimes modify the downward or leeward streaming, thus producing rills of our third type. Finally, the rills may be more or less completely smoothed out by wind erosion, producing our fourth type.

The rills on the Chilean meteorite (Palache, 1926) are difficult for us to explain. It may be that an octahedral etch pattern developed through oxidation of troilite, and then was smoothed out and partially obscured by wind erosion.

It may be that both these meteorite rills and the limestone and gypsum rills of our fourth type are entirely the result of wind erosion. However, the existence of gradations to our other types causes us to incline to the opinion that fourth type rills are formed by the wind from pre-existing rills of the other types.

ACKNOWLEDGMENTS.

The incentive to make this study of *Rillensteine* came from Mr. Richard Bramkamp of Claremont Colleges, who was making a survey of various California limestone deposits for the Riverside Cement Company. We are also greatly indebted to Professor Eliot Blackwelder of Stanford University, especially for fine specimens from Death Valley and for an illuminating discussion of their significance, and to Dr. R. D. Reed of the Texas Company, for rilled limestone from Death Valley and rilled gypsum from Texas. Specimens, information or criticism have also been furnished by Mr. Alden Packard, Mr. Paul Teas of Colorado, Texas, Dr. R. B. Stewart of the U. S. Geological Survey, Professor P. A. Munz, Dr. W. G. Leighton and Mr. Alton Kurtz of the Claremont Colleges, Mr. Clifton Johnson and Dr. P. L. K. Gross of the California Division of Water Resources, and Professor A. C. Lawson, Professor Loye Miller and Dr. Charles Anderson of the University of California.

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Claremont, California.

CONTRIBUTIONS TO THE STUDY OF MOUNTAIN-BUILDING.

JAY BACKUS WOODWORTH.

EDITED BY A. C. SWINNERTON.

I. The Orogenic Cycle.
II. The Relations of Igneous Rocks to Mountain-building.
III. Appalachian Mountain-building.

EDITOR'S INTRODUCTION.

When Professor J. B. Woodworth died in 1925 he left a quantity of notes on the subject of mountain-building. His views were based on an extensive acquaintance with geologic literature and on his long-continued field-work in the Rocky Mountains, in New England, and in the southern Appalachians. The editor, as a graduate student in structural geology under Professor Woodworth's direction from 1919 to 1922, became intimately acquainted with the ideas dominating the mind of his instructor. At the suggestion of R. W. Sayles of Harvard University and of Arthur Keith of the National Research Council, the compilation of Professor Woodworth's notes was undertaken.

The ideas here presented are taken as nearly verbatim as possible from the Woodworth writings. The most copious notes are concerned with various theoretical approaches to the central idea of the mountain-cycle. A note-book listing data from all parts of the world was begun, but the facts entered therein are fragmentary and references are largely omitted. It is much easier and perhaps wiser, to present the ideas for the most part unsupported and let them be considered for whatever value they may have rather than try to supplement the beginnings of what might have been a monumental work had Professor Woodworth lived to complete his task.

It is scarcely necessary to add that the conversion of disconnected, rough notes into a form suitable for publication, exhibiting balance and continuity, has not been done without considerable effort. Affection and respect for Professor Woodworth have actuated the undertaking and are the guarantee of a sympathetic interpretation which would attempt to present his views with the minimum of injustice. R. W. Sayles, Arthur Keith, and

Charles Schuchert should be given appreciative mention for reviewing the manuscript and making suggestions, but the editor must assume responsibility for the interpretation here presented.

Only two publications in the field of mountain-building issued directly from Professor Woodworth in recent years: the first an abstract[1] in the Bulletin of the Geological Society of America, the second his paper on the Cross-section of the Appalachians in southern New England,[2] which was published in full in the same bulletin. Neither of these gives the sum of his views in regard to the cyclic events and the extent of mountain-building, although one familiar with his ideas can read much of them between the lines in both of these publications.

I. THE OROGENIC CYCLE.

Introduction.

"For several years prior to 1919 I came to regard the so-called 'fault-block' mountains of the Great Basin and Cordilleran region of western North America as the equivalent in geological structure and process to the late Triassic—'Newark'—areas of the Appalachian region of eastern North America, and to perceive that both of these tracts of normal faulting of the tension type with their dominantly basaltic lavas stood in relation to the folding of geosynclinal accumulations which preceded them as concluding parts of a grand succession of diastrophic changes in the earth's crust, causally and in every way a part of the problem of mountain-building."[3]

General Statement of the Orogenic Cycle.

The Classical Views. In all mountain-built regions the period of sedimentation which preceded the diastrophic crisis implies the prior existence of a land area. Where the unconformities are now visible there is found the implication that this early land area experienced a physiographic development which resulted in a surface of low relief. In most instances this geological development, antedating the initial mountain-building activity, may have reached the stage aptly called a peneplane.[4]

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[1] Relations of fault-block mountains to folded chains. (Abstract) Geol. Soc. Am. Bull. 31, 115-116, 1920.

[2] Geol. Soc. Am. Bull. 34, 253-261. 1923.

[3] Quoted directly from Professor Woodworth's note-book.

The land surface developed on the inert crust becomes initially involved in mountain-building activity by the differential crustal movement resulting in the invasion of marine waters in a trough-shaped depression bordering a land area. Such a depression is a crustal syncline of deposition—the geosyncline of James D. Dana. The bordering land area may be called the geanticline of erosion. The activity of these two phases—erosion and deposition—continue with varying intensity for a considerable period of time and is accompanied by the progressive depression of the geosyncline.

Toward the end of the stage of geosynclinal accumulation crustal compression makes itself felt by the beginnings of folding in the strata deposited in the geosyncline. The folding, thus initiated, continues sporadically for a considerable time (although it must be considered relatively short when compared with the depositional phase), increasing in activity and violence until the final violent stage of overthrusting and extreme folding brings the compressional episode to a close. Partial and incomplete peneplanes will mark the erosional activity in any premature orogenic developments and in the growing mountains of the final compressional episode. Following the crisis of the compressional activity a prolonged period of base-leveling may develop an extended peneplane on the "new-land" of deformed and dislocated sediments and also over the geanticline of erosion—the "old-land."

The Complete Mountain-cycle.

Block-faulting. The preceding account of mountain-building constitutes the accepted sequence of orogenic developments. To it should be added the sequence of a stage of tension in the crust which results in faults of the gravity type. It is not uncommon to find that these crustal segments give rise to block-mountains. Such faulting is to be found both in the folded and dislocated new-land and in the old-land as well.

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[4] Professor Woodworth insisted that the term peneplain should be spelled "peneplane" since the ultimate stage of erosional activity was a plain. The use of the prefix "pene-" implies the approach of this plain not to a geographic plain but to the more ideal geometric plane. In deference to his opinion the spelling which he preferred will be used in this article.

It is impossible in this summary to cite all the illustrations of folded mountain chains in which there has been the sequence of normal faulting. In North America the outstanding illustrations include the Triassic deposits scattered throughout the Appalachian region, and the Great Basin Range structures of the western Cordillera, with which should be included the intermontane basin deposits of the northern Rocky Mountains and probably the trenches of the Canadian Rockies. It is not impossible that the Keeweenawan series of the late pre-Cambrian finds a similar relationship to earlier pre-Cambrian mountain-building; likewise the flat lying non-marine Pennsylvanian rocks of New Brunswick. In Europe the Permian beds of Germany, France, and Russia, the Triassic deposits of Central Europe, and the down-break of the Rhine Valley are similar structures and may be cited as illustrations of the tension phase of the crustal forces following a compression phase.

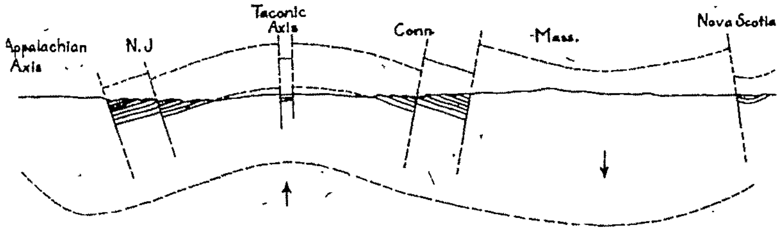

Fig. 1. Generalized cross-section to show a theoretical interpretation of the Triassic structure across the New England mountain-built terrane.

Triassic block-faulting in the Appalachian region illustrates in a most excellent manner the association of normal faulting with an extended tectonic area. Russell long ago discussed the distribution of the Newark deposits. Whether they be regarded as continuous beds preserved by infaulting or whether they are isolated basin deposits, is immaterial in the present discussion. The important consideration is that they are found throughout the Appalachian region as a characteristic feature. In fact, they are as typical of the Appalachian region as the folds and overthrusts themselves.

Normal faults may occur beyond the belt of folding. In the Rocky Mountain region normal faults are found south of the Mesozoic rocks in the plateau region of Arizona where faults and flexures (the monoclines of Powell) are the differential effects of block uplifts and depression. In general the faulted areas appear to be larger than those areas which have been folded in the early part of the cycle.

Normal faults also occur in the regions in which there has been no prior folding in the same field. Care should be taken to recognize that the scheme presented in this paper has limitations, and to bear in mind that normal faults do occur in districts where it is by no means evident that folding induced by compression has preceded the faulting phase. The great rift valleys of Africa stand out as striking examples of normal faulting in recent geological times without trace of folding since the pre-Cambrian.

Igneous Rocks. Attention should also be called to the relation of igneous rocks to the contrasted compressional and tensional phases of mountain-building. In the first stage igneous activity is almost entirely confined to acid intrusions in the form of batholiths and laccoliths. The igneous activity of the tensional stage is characterized chiefly by dikes, sills, and lava flows of the basaltic or basic type. These relations are considered in greater detail in Part II.

The Migration of Geosynclines. One further item which needs to be considered in the mountain-cycle is the appearance of tectonic sub-cycles. The initial sedimentary activity may be varied by the migration of the site of maximum deposition and in places may be interrupted by the premature compressional activity of the orogenic forces. The classic geosyncline of the southern Appalachians exhibits little in the way of marked interruptions of the sedimentary deposition.

But such activity is seen particularly in the mountain-building developments in the Maritime Provinces. Elsewhere will be discussed the southeastward migration of the geosynclines in that region. The presence of probable Taconic folding in western New England was followed by late Carboniferous in eastern Massachusetts; and, in the southern Appalachians, deposits on the eastern side of the classic geosyncline, in the early Paleozoic, were succeeded, in late Paleozoic, by a westward migration of the site of maximum deposition.

Corollaries of the Mountain-cycle.

Sedimentary Facies. Not only do igneous rocks differ in the contrasting phases of mountain-building but there is likewise a differentiation in the sedimentary rocks, resulting from the appropriate depositional environments. During the early stages of the compressional phase the off-shore deposits will consist of a gray and green series of quartz-sandstones, shales, and limestones. At the end of the compressional phase the coarseness of sediments will be somewhat increased. During this latter stage land sediments will consist of tillites, greywackes, and coal beds marking the various environments—glacial, fluviatile, lagoon—from the growing mountains to the sea border.

During the tensional stage the off-shore sediments will first of all consist of red sandstone and shale, the red coloration of which results from the long-continued oxidation of the land-surface materials during the formation of the post-compressional peneplane. These red-beds may be followed in turn by the encroachment of the usual type of coastal plain deposits including chalky limestone. The land deposits of this phase, will include intermontane basin deposits: arkose, greywackes, and various conglomerates, sandstones, and shale, with red-beds of the desert type, and beds of detrital volcanic material.

Gold, Copper, Coal. Economically valuable materials, representing the results of geologic activities which are characteristic of phases of the mountain-cycle, may be related systematically to the orogenic-cycle.

Gold-bearing quartz veins occur most frequently in connection with the acid, granitic intrusions associated with the stage of compression accompanied often by extensive contact metamorphism at considerable depth below the constructional surface of the time. Such auriferous veins are not wanting in the crystalline schists of an older orogenic episode lying below the antecedent peneplane (unconformity) of the folded stratified rocks of a later mountain-cycle.

Ores of copper, including native copper, are frequently associated with the basic effusives of the final stage of the mountain-cycle with its non-marine red-beds and fault-blocks. The copper ores in many areas may be regarded as the accompaniments of the ascending basic magmas. Elsewhere the deposits of contact metamorphic nature may be related to the more acid intrusives of an earlier stage of the mountain-cycle.

Deposits of lignite, bituminous and anthracite coal are found invariably in mountain-built districts interbedded with the non-marine strata of a greywacke facies deposited immediately before the episodes of folding and intrusion, during the episode of accelerated uplift in the old-land area which precedes the compressional collapse.

Coal deposits likewise may occur in the red-bed and basaltic-effusion stage following on the breaking down by faulting of the eroded district of uplifted folded strata and adjoining old-land. Such was the case in the upper Triassic or Newark beds of the Appalachian area. Here again, similar causes produce like effects; the rapid erosion and resulting deposition of non-marine sediments consequent on the accelerated uplift of fault-blocks on one side and the downthrow of basin-blocks on the other provide opportunities for the rapid burial and preservation of vegetation in moist or water-laden tracts. Whether the vegetation giving rise to coal grew in situ or was floated into its place of burial is a detail not affecting this generalization which deals with the broader problem of time and phase of development.

Physiographic Phases. Physiographic developments may also be related systematically to the orogenic changes. The antecedent peneplane has already been mentioned. At the close of the compressional episode the characteristic drainage will be consequent, followed by subsequent adjustments of the tributaries and minor streams although the strongest major streams will maintain their consequent courses. At length a peneplane is developed. During the period of normal faulting superposed drainage will be characteristic in many instances. There will follow another extended peneplanation of the mountain-built region.

In the physiographic history of the orogenic cycle four sets of peneplanes are to be noted. They may be designated in chronologic order: the antecedent peneplane which precedes the geocyncline; the antepenultimate peneplane or peneplanes to be found incompletely developed in the growing mountains; the penultimate peneplane which marks the stage of equilibrium between the compression and tension phases; and last the ultimate peneplane which characterizes the final stage in the mountain-building cycle.

A tabular view of these relationships follows:

Orogenic Cycle and its Corollaries

	Diastrophism	Vulcanism	Erosion on Land	Sedimentation of all Types	
				Inland	Marine (Littoral)
Tension			ultimate peneplane	(little or none)	*Coastal Plains* limestones (chalk)
					red sandstone shale
	normal faulting (cooling)	basic effusives and minor intrusives	superposed drainage	ash beds red-beds conglomerates sandstone shale arkoses greywackes	
equilibrium			penultimate peneplane	(little or none)	red-beds sandstone shale limestone
Compression	overthrusting after folding	acid intrusives (batholiths and laccoliths)	consequent drainage	tillites greywackes coal beds	
	(heating)				*gray and green beds* conglomerates sandstones (quartz) shales limestones
			antecedent peneplane		

II. THE RELATIONS OF IGNEOUS ROCKS TO MOUNTAIN-BUILDING.

Introduction. Harker and others have called attention to the association of granitic intrusives as typical batholiths with areas of folded strata in mountain-built tracts, and of great outflows and minor intrusions of basalt and allied basic magmas with the areas of normal faulting and contemporaneous terrestrial sedimentation. It remains to observe in the same tectonic area the succession of (1) folded strata invaded by granitic masses and (2) faulted structures involving newer sediments and basaltic flows and sills contemporaneous with those sediments.

Areas in the Canadian pre-Cambrian, in the Appalachians, in the Cordilleran districts of North America as in the Sierra Nevada, the Laramide and the Coast Ranges, and in the South American Cordillera have had their compressive episodes accompanied by acid intrusives. Illustrations of the same sort might be presented from nearly all tectonic regions. Examples of the basic association were given earlier.

Location and Source of Igneous Rocks. The batholiths of acid magmas invade chiefly the rising land and fresh-water sediments in the geanticlinal tracts and avoid the troughs of thick marine sediments; as witness the unintruded geosyncline of the Appalachian folds in Pennsylvania and southward. Likewise the later dikes and sill-forming basic magmas issue as lavas principally in the old geanticlinal areas of erosion as in the Newark areas of the Appalachian field and the Keeweeawan district of Lake Superior.

The acid stocks and batholiths frequently occur as intrusions in ancient crystalline schists forced up in the rising mid-axis of the mountain-growth. The magma originates probably in or below these ancient schists of complex origin. There is little or no evidence of the derivation of the magma from melts of sediments laid down in the early part of the cycle of mountain-formation. The magma is of deeper origin. The deepest sections exhibit intrusive contacts however much the country rock may have been absorbed. The fact that the magma at the early stage is acid and that the later basaltic magma rises in the same field through the same schists and through the cooled and faulted stocks and batholiths points to a deep-seated origin below the zone of metamorphosed rock for both acid and basic magmas. It may be inferred therefrom that the granite-rhyolite magma is the upper differentiate of a common initial magma forced up in the compression phase, while the more fluid basaltic magma comes up later under the gravitational adjustment of broken and settling fault blocks.

The Sequence of Acid and Basic Types. The much discussed question of the sequence of the contrasted types of igneous rocks—those of the granite-rhyolite family at one extreme of the group, and basalts and kindred types at the other—is within the proper field of the structural geologist so far as the relations of rock bodies and the order of their intrusion, as determined by the facts of contact and intersection, are concerned. It seems impossible to begin at the beginning since the attempt to determine which comes first in the pre-Cambrian sections is usually unsatisfactory for the reason that there is in most pre-Cambrian sections a lack of evidence as to the nature of the rocks underlying the visible portions of the earth's crust. A basic series of eruptives may have been preceded by a now-buried acid series in the closest relations as regards time and place, or the granite-gneiss of a batholith may have followed a basic eruption. It would appear more reasonable to start with the close of a series of eruptives in a region of vulcanism and mountain-building, which comprised episodes of folding and faulting, and proceed downward in the section and backward in time. When this procedure is adopted in North America, in regions in which the hypogene activities producing the vulcanism and diastrophism have long been dormant, the order of succession is invariably such as to support the statement that acid eruptives in the form of granitic batholiths immediately precede great basaltic eruptions. The word "immediately" is employed here in a relative sense only and with regard to the whole duration of the tectonic cycle. The interval may be as long as two-thirds of one of the variable divisions of geologic chronology called a period.

Relation of Basaltic Extravasations and Fault-blocks. The great basaltic outpourings of the Newark group, in the Keeweenawan group in the pre-Cambrian Huronian mountain system, and the lava floods of the western Cordilleras, are involved in "Great Basin Range" structures, i.e. areas of fault-block mountains or their worn-down remnants.

That extravasation of the basic magma did not in any large way cause the crust to break up and fall in as tilted and settled blocks separated by normal faults is shown by the relatively small amount of basalt involved in the large displacements of the Great Basin Range structures of Nevada and adjacent tracts. There is in that vast field no evidence of any adequate volume of magma which moved from a subcrustal reservoir to the surface to account for the phenomena of fault-collapse of the crust and the differential settling or tilting of the crustal blocks.

Causal Relations. A few broad generalizations lie on the surface of the succession of phenomena in the mountain-cycle. First, it would seem that the appearance of acid magmas in the stage of compression and folding was preparatory to the coming out of the basic magmas in the succeeding stage of normal faulting. Second, the sudden appearance of these contrasted types at the crisis of folding on the first hand, and of normal faulting in the second stage, may be more apparent than real. The deep-seated evolution of the acid magma may be correlated in time with the formation of the geosyncline of deposition and the contiguous geanticline of erosion in which latter area the batholiths chiefly occur. The formation of the acid magma and the upward migration may well have begun very early in the sequence of geological changes with which it is so intimately associated in time and place.

Differentiation. Any interpretation of this occurrence of the contrasted types of igneous magma in the same dynamic field leads at once to the question of the origin of acid and basic magmas and the differentiation of an ideal primitive magma. That differentiation of some kind takes place in the molten matter which migrates to or towards the surface, first as a granite in the compression stage, and second, after a period of erosion, as basaltic magma in the stage of normal faulting is evident because of the repetition of this succession of magmas in the course of the complete mountain-cycle in different ages, not only in different tracts of the continents but in the same districts. The inference therefrom seems evident that the differentiation of magmas, in these instances at least, is intimately bound up in the problems of the formation of mountains, first as folded strata and secondly as faulted blocks in the same dynamic field.

Relations of Acid Intrusions to Folding. Since igneous activity is associated with the culminating phases of the folding and overthrusting of the early stage, it is not unreasonable to attach a causal relationship to the association in looking for the solution of the mountain-building problem. Is one the result of the other or are both the result of a common cause?

If the batholithic intrusions and the folding, which is a manifestation of compression, are causally related, the two phenomena may be regarded as due to the squeezing together of the pliable strata and the fluidal magma by earth pressure arising from a cooling and contracting globe. Or, the logical alternative: due to the sporadic rise of the acid magma in the crust with exhaustion at the cooled extremities of the intrusion, but continuing activity at depth, crowding and dislocation of the strata of the geosyncline result. The accelerated rate of erosion just before folding occurs is undoubtedly causally related to the magmatic movement, but beyond this no definite conclusion is justified.

III. APPALACHIAN MOUNTAIN-BUILDING.

Historical Introduction. The first view of the Appalachian structure was that given by William B. and Henry D. Rogers who revealed the folded strata of the Appalachian Mountains. James Hall of the New York Geological Survey recognized the synclinal nature of the tract, but it was James D. Dana who named the great down-fold in the earth's crust with its contained folded and overthrust Paleozoic strata a geosyncline. Bailey Willis later published an experimental elucidation of the manner in which lateral pressure, suggested a century before by James Hall of Scotland as the cause of folded strata, might have worked to produce the peculiar deformations and displacements such as are found in the strata of the geosyncline. Such were the steps in the American conception of the origin of the folded chain, during the last half of the nineteenth century.

Limitations of Classical Appalachian Theory.

The hypothesis of mountain-building based on the southern Appalachians dwelt on excessive sedimentation not far offshore; and the later recognition of a few unimportant dikes of basic igneous rocks cutting the strata in the disturbed area, gave no ground for granting that igneous intrusions on a larger scale had played a significant role in the dynamic problems of mountain-building.

In the minds of most workers on the problem, the nineteenth century view of Appalachian structure considered only a narrow terrane of little-metamorphosed strata on the west of the Blue Ridge. In the later stages of the concept a belt of basal metamorphic rocks and igneous intrusions in the Blue Ridge and in an indefinite strip of country in the Piedmont region on the east was admitted as having participated in the general process of mountain-building. East and northeast of these tracts the complicated rock structures of the Piedmont and New England were omitted from the statement of the problem partly because of a lack of clear comprehension of the geological history of this difficult region.

The theory of mountains based on the southwestern Appalachian district did not take into account, and left unaccounted for, by far the greatest part of the mountain-built eastern border of the continent. It left out of consideration entirely the role of igneous intrusions so evident in the Rocky Mountains, in the Andes and all the mountainous districts of the past—thus failing to afford a satisfactory explanation of mountains in general. When the student, brought up on the Appalachian hypothesis, confronted the Rocky Mountains with a great uplift of pre-Cambrian granites and crystalline schists at the very edge of the mountains, he felt there was something radically wrong about his theory of mountains and that he had entered on a part of the world where Appalachian mechanics did not apply. Likewise the student of New England geology beholding mountain-built Carboniferous strata in southeastern and eastern New England realized that the old theory did not include the patent facts of that mountain-built region which was, nevertheless, part and parcel of the diastrophic movements taking place at the close of the Paleozoic in the northeastern part of North America. The reason for this limited and one-sided view of the Appalachian problem in the district south of New York arose from the fact that east of the Blue Ridge the identified rocks of the Paleozoic afforded no trace of fossils more recent than the Ordovician, and that east of the Piedmont district these ancient rocks are lost to view under the coastal plain of the Cretaceous and Tertiary strata.

Because of the fact that rocks of the Piedmont district were scarcely distinguished from the pre-Cambrian rocks antedating the deposition in the geosyncline, and that east of the Piedmont the Paleozoic and older rocks were concealed beneath the coastal-plain of Mesozoic and Tertiary strata, attention was rivetted on the western side of this section and no thought was taken of any diversity of structure on the east of the typical section of the Appalachian Mountains. The westward overturning of folds in the classic geosyncline and the overthrusting of beds in the same direction gave rise to such conceptions as pressure from the Atlantic basin and a general westward overthrust in the surficial section of the earth's crust and also the possibility of underthrust to the east. If the Appalachian structures are admitted to be more widely extended than formerly believed, then the inferences in regard to the orientation of tectonic forces need to be reconsidered.

Extent of Appalachian Orogeny.

Four lines of argument emphasize the extent of the Appalachian folded area: (1) the great lateral extent and complex character of the mountain-built areas of New England and the Maritime Provinces implies greater breadth in the southern district; (2) the sinuous, arcuate structural pattern displayed in the southern Appalachian and more broadly in the northern district disappears beneath the coastal plain sediments east of the Blue Ridge; (3) the acid intrusions and the crystalline "old-lands" which commonly occupy an axial position in mountain-built areas and are roughly so located in the northern Appalachians, lie at the east edge of the visible mountain-built area in the south; (4) normal faulting and associated basic intrusions and extravasions occur throughout both parts of the Appalachian province but particularly near the east border in the southern Appalachians. See Fig. 2.

The resemblance of the arcuate pattern of the geological map of the eastern North America to the alpine arcs of southern Europe is probably quite as real as it is readily perceived; but the American arcs pervade the entire breadth of the existing mountain belt from the western border to the coast, where the structures are lost to view beneath the sea or concealed by the Atlantic coastal plain. The true eastern limit of the Appalachian deformation of North America is not known. In the New England district and the Maritime Provinces of Canada is found a broad outcrop of formations which are concealed on the south by the coastal plain. In this northeastern extension of the area of diastrophism there lies a district more in keeping with the broad mountain-built zone of the same period in western Europe.

In the northeastern district above described there was not one geosyncline, but several similar troughs of deposition filled as they sank in the earth's crust in successive stages. In the Acadian and Gaspesian region a Cambrian-mid-Devonian trough (St. Lawrence Geosyncline of Schuchert) of marine sediments which developed off, and perhaps on, the southeastern border of the Canadian shield along the axis of the present

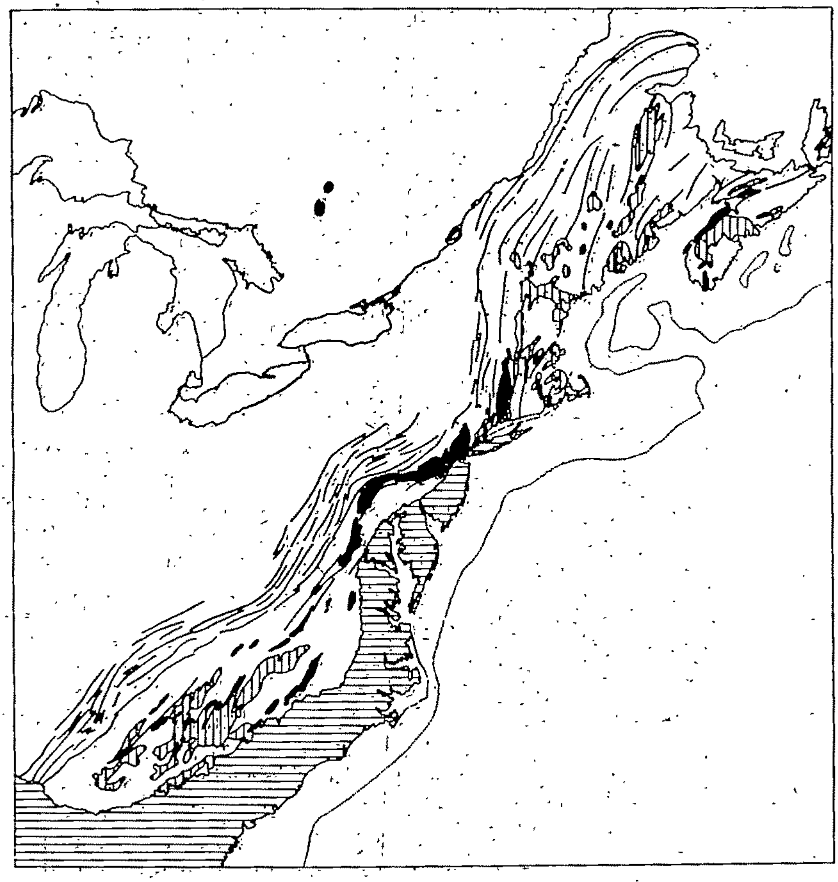

Fig. 2. Generalized map of the elements of the Appalachian mountain-built district in eastern North America. (Adapted from Willis, U. S. G. S. 1912.) Dotted line is the hundred fathom line. Horizontal ruling, the coastal plain, including Long Island and Cape Cod; vertical ruling, late Paleozoic intrusives; solid black, Triassic deposits; curving lines indicate in a generalized fashion the trends of the Paleozoic and probable Paleozoic structures. This figure attempts to delineate the Woodworth argument for the greater lateral extent of the Appalachian terrane in North America.

St. Lawrence Valley collapsed in the mid-Devonian. The crumpling was accompanied by granitic intrusions in the area on the south. Erosion set in and on surfaces reduced to something like a peneplane, deposition ensued, bearing sediments probably from the rising cuestas of tilted fault-blocks. A Carboniferous (Alleghanian) trough formed on the southeast over the site of the older Acadian geosyncline, filled with sediments, and was flexed, somewhat eroded and covered unconformably by late Pennsylvanian beds. In the Upper Trias, red-beds with trap flows covered the Bay of Fundy region, and were faulted downward on the west side. In this eastern region the site of troughs of deposition and the mountain-building changes appear to have progressed southeastward.

The arcuate basins of infolded and downfaulted sediments of southeastern Massachusetts, concave to the southeast, present a strongly marked instance of the horizontal disposition of folding with varying radii of curvature which is characteristic of the entire length of the Appalachian chain from Gaspe into the southern states. Undoubtedly these sinuous strikes in the deep-seated structure of the range, are an expression of the whole orogenic region. Their rude parallelism across the entire belt is reflected, south of New York, in the conformation of the curvatures of the present coast line to those of the Appalachian folds on the western side of the district in the typical or classical American geosyncline. It is distinctly unreasonable to suppose that these flexures do not continue beneath the little disturbed Coastal Plain sediments.

The rôles of igneous activity and of normal faulting in demonstrating the extent of the Appalachian tectonic region have been dealt with as part of the larger problem of their relations to the orogenic cycle. But it should be re-emphasized in this instance that whereas the areas of Triassic rocks lie in various geographic relations in the northern Appalachians, on the east and west borders and in the central area, in the southern district the Newark, Gettysburg, and Richmond basins lie in the down-broken Blue Ridge or the Piedmont, near the Coastal Plain overlap. The suggestion is therefore strong that the mountain-built area extends further eastward under the more recent sediments.

EDITOR'S CONCLUSION.

Early in the development of American thought in regard to mountain-building the events of the Appalachian orogeny came to be considered as a basic hypothesis for all mountain-building. In Professor Woodworth's use of the term "Appalachian hypothesis" is found the connotation of something resembling a universal hypothesis. In his thinking it is apparent that the Appalachian hypothesis might well retain its rightful place as a basic mountain-building theory if the extent of geologic activity, space, and time of the Appalachian orogeny be given adequate consideration.

The extent in activity includes the recognition of the rôles of igneous rocks and of the tension phase which results in normal faulting. The extent in space implies the proper inclusion of the northern Appalachian area in the problem and the eastward continuance of the southern Appalachians through the Piedmont district and under the deposits of the Coastal Plain.

The extent in time requires the consideration, not only of the addition of the tension phase to the mountain-building sequence, but the recognition of the cyclic nature of the events progressing from one developed land-surface on an inert crust through a variety of happenings to an ultimately developed land-surface again a part of the inert crust. All these elements were, in Professor Woodworth's mind, "..........parts of a grand succession of diastrophic changes in the earth's crust, causally and in every way a part of the problem of mountain-building."

PREPARATION OF THIN SECTIONS OF PORTLAND CEMENT AND OTHER CLINKERS FOR PETROGRAPHIC EXAMINATION.

H. G. FISK

Thin sections of portland cement clinker, when prepared in the ordinary way, have two disadvantages. In the first place, the refractive index of Canada balsam, 1.53-1.54, is very much lower than that of most of the clinker minerals, above 1.70, and the great difference in refractive index of the imbedding medium and the minerals causes the thin section to exhibit a very high relief and makes difficult the desired comparisons and observations.

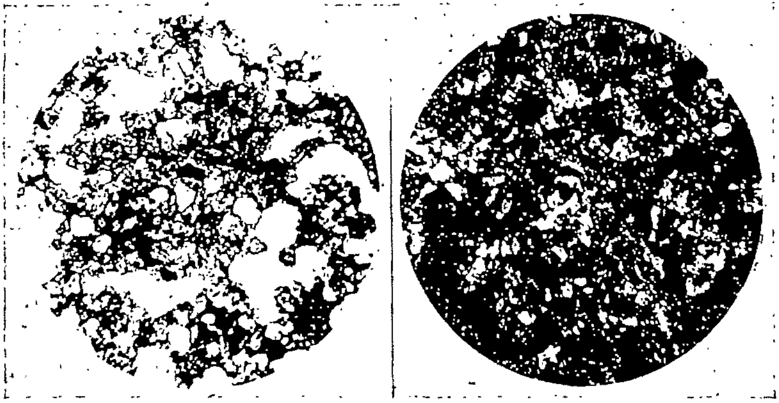
Fig. 1 Fig. 2

Fig. 1 is a photomicrograph taken in ordinary light of a thin section of portland cement clinker prepared and mounted in Canada balsam. The extreme relief of the minerals is apparent.

Fig. 2 is a photomicrograph of the same field as that of Fig. 1 between crossed nicols. The turbid appearance of the section caused by partial hydration may be seen.

In the second place, in preparing the section when grinding is done by means of abrasive grains with water as a lubricant, some of the minerals in clinker react with the water and partially hydrate. This often causes portions of the thin section to be clouded with a zone or layer of hydration products. In the case of portland cement clinker, these hydration products consist of aggregates of tiny crystals, many of which are thought to be tricalcium aluminate hydrate (mean refractive index very close to balsam), and make it questionable whether some of the compounds, such as tricalcium aluminate, may not be largely, or completely, removed by hydration.

Bakelite (1) has been applied in the impregnation and preparation of thin sections. Its use largely overcomes the difficulties mentioned, and it has distinct advantages over Canada balsam, but when hardened its refractive index does not exceed 1.64, still appreciably lower than the silicates and aluminates in portland cement clinker. Also the use of bakelite requires considerable care and over two days' time for hardening, if satisfactory results are to be had with it.

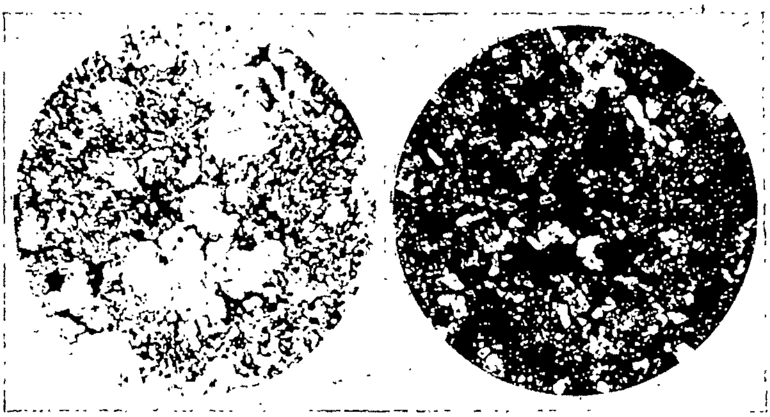

Fig. 3 Fig. 4

Fig. 3 is a photomicrograph of a thin section of clinker similar in character to that of Figs. 1 and 2, but prepared and mounted in hyrax. The low relief of the silicates makes possible the use of the Becke reaction to determine relative refringence of the minerals.

Fig. 4 is a photomicrograph of the same field as shown in Fig. 3, between crossed nicols.

The writer has found that a new synthetic resin recently placed on the market and sold under the name of "hyrax"[1] can be used to overcome the disadvantages mentioned for Canada balsam and bakelite. Hyrax has been employed by Hanna (2) as a mounting medium for diatoms. When properly cooked hyrax has a refractive index of about 1.70 to 1.71 and can be used in much the same way as balsam. It also has the decided advantage of being insoluble in ethyl alcohol, thus enabling grinding of the specimen to be done in this medium in place of water, which eliminates the reaction of clinker minerals and water. It is, however, possible to grind sections mounted in balsam with non-aqueous liquids, such as certain oils (3).

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[1] Hyrax, according to the manufacturers, is a definite compound of naphthalene and is usually furnished dissolved in benzol—it can be procured from Eimer and Amend, New York.

Hyrax is usually procured dissolved in benzol, and it is necessary before using it for mounting a specimen to cook it in order to harden it and increase its index of refraction. This can be carried out on a watch glass in a constant temperature oven maintained close to 100° C., preferably slightly below this temperature. The cooking treatment requires from ten to twenty hours. From time to time a small amount of the hyrax may be withdrawn and tested after cooling. It has been found that satisfactory results are obtained if the cooled material is slightly plastic, but not sticky. After being cooked to the proper consistency, the hyrax can be gathered on a cool glass rod or poured onto a chilled glass plate and broken up and put into a suitable glass receptacle.

In preparing thin sections of most clinker samples or other more or less porous or cellular material, it has been found advantageous to first impregnate the specimen. This can be done by roughing out the section dry until it is about one-eighth to one-quarter inch thick and placing it on a hot plate. As the specimen heats, small fragments of hardened hyrax are flowed into the upper surface and allowed to fill the pores. For this purpose it has been found satisfactory to employ hyrax which has been cooked beyond the stage where it is useful as a mounting medium, that is, when it is brittle and amber colored. After the surface impregnated is fairly well soaked, the fragment is removed from the hot plate and allowed to cool, impregnated side up. More warmed hyrax can be rubbed into the surface during cooling, if necessary, to fill large voids.

After cooling, the impregnated side of the specimen is ground down on a glass plate with "F" grade carborundum, using ethyl alcohol as a lubricant.[2] When examination shows that the ground side is essentially flat, the specimen is rinsed in alcohol and grinding is continued with "400" carborundum. Finally, after rewashing, the specimen is further ground in a similar manner with "600" carborundum. A camel's hair brush and alcohol assist in removing abrasive from newly opened pores brought about by grinding. The final grinding is done on a special glass plate used only for that purpose with "M 303" optical emery. After the specimen has been thus prepared for mounting it is again washed with fresh alcohol and allowed to dry in the air without heating. In the meantime a glass slide is prepared by warming on a hot plate and some cooked hyrax is placed on the center of the slide. It is very difficult to get bubbles entirely out of the hyrax on the slide but manipulating the slide with tweezers, causing the molten resin to flow around, assists. However, it is not absolutely essential to remove all bubbles, as most of them can be worked into pores after placing the specimen on the slide, while the resin is still plastic.

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[2] Government absolute alcohol denatured by formula 2-B is satisfactory for grinding.

The impregnated and ground side of the specimen, after thorough air drying, is placed face down on the molten hyrax and manipulated with gentle pressure until it is flat on the slide and most of the bubbles have been worked from under it. At times it is necessary to remove the specimen and repeat the mounting operation to get a satisfactory contact, between slide and specimen.

After mounting, grinding of the section to the necessary thinness is conducted in the usual manner, except that ethyl alcohol is used in place of water. Final grinding is done with "M 303" alundum.

When the section has reached the desired thinness, as determined by microscopic examination, it is ready for mounting the cover glass, which operation is confronted with certain difficulties. In the first place, most clinker samples, when sufficiently thin, are quite porous and friable. If previously hardened hyrax is melted on the slide with the specimen, the latter is almost sure to disintegrate. Some hardened hyrax can be melted on the cover glass, and this inverted on the specimen, but this procedure usually causes difficulty. If hyrax is dissolved in the usual solvents, toluol, xylol, benzol, etc., the advantage of its high refractive index is largely counteracted due to the diluting effect of a solvent with a low refractive index. For these reasons a solvent with a high refractive index was sought, and found in methylene iodide, the refractive index of which is about 1.74. Cooked hyrax appears to be miscible in all proportions in methylene iodide. For the purpose of mounting the cover glass a drop or two of a fairly thick solution of hyrax in methylene iodide is introduced on the center of the ground section and allowed to run over its surface. A slightly warmed clean cover glass is then placed over the section starting from one side at an angle with the plane of the slide. The methylene iodide-hyrax solution has excellent penetrating and covering power and by its use a satisfactory mount is obtained. A slight weight or pressure on the cover glass causes any excess of mounting medium to be expressed from beneath the cover glass whence it can be removed. Gentle warming may be applied to the mounted slide to assist in fusing the undissolved hyrax with the liquid portion and to bring about homogeneity. If the covered section can be left in the air for one or two days, the methylene iodide volatilizes sufficiently around the edges of the cover glass so that it remains in place on the specimen. It has been observed that the mounting medium, when methylene iodide is employed as solvent, darkens somewhat on continual exposure to light, but this effect does not seem objectionable when the section is examined by strong artificial light under the microscope.

The accompanying photomicrographs show thin sections of a portland cement clinker prepared in the usual manner and a clinker of similar composition and texture prepared in hyrax.

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BUFFINGTON, INDIANA.

SCIENTIFIC INTELLIGENCE.

CHEMISTRY AND PHYSICS.

Colloid Chemistry; Theoretical and Applied. Volume III, Technological Applications. Collected and edited by JEROME ALEXANDER. Pp. 655, with figures. New York, 1931 (Chem. Catalog Co., price $10.50).—Mr. Jerome is to be congratulated on having again assembled a noteworthy series of contributions on colloid chemistry, written in many cases by distinguished specialists. Neither here, nor in any of the volumes, is there an attempt toward a systematic treatment of colloids, but each volume consists of separate articles which appear to have been chosen by the individual writers. The present volume consists of forty-two such contributions, which cover almost as many different fields of colloid chemistry. Anyone with even a mild interest in the subject will find many of the articles exceedingly interesting and suggestive. The high price of the book is to be regretted.

H. W. FOOTE.

Katalyse vom Stand-punkt der chemischen Kinetik; by GEORG-MARIA SCHWAB. Pp. viii, 249; 39 figs. Berlin, 1931 (Julius Springer, price 18.60 Rm., bound 19.80 Rm.).—There is perhaps no more fundamentally important subject in the whole of chemistry than catalysis. Catalysts—substances which, by their presence, affect the speed of a chemical reaction—are essential to every living organism, and in many important chemical industries. Some of the principles of catalytic action have been well understood for many years. For instance, in most cases it is quite possible to predict whether a given reaction can, or cannot, be catalyzed. The difficulty has been, and still is, to predict what catalysts will be efficient, and this is largely because so little is known as to how a catalyst acts and what the mechanism is.

Dr. Schwab has presented, in this book, an excellent account of our present knowledge concerning catalysis, laying emphasis on the experimental facts on which general principles and explanations must be based. It must be confessed that experiment is far ahead of theory at present. Homogeneous gas catalysis, catalysis in solution, and heterogeneous catalysis, are the main topics considered.

H. W. FOOTE.

Enzyklopädie der technischen Chemie; 2nd Ed., Vol. VII. Pp. iv, 866; 318 figs. Berlin and Vienna, 1931 (Urban and Schwarzenberg, price 45 Rm.).—This splendid encyclopaedia is now about three-quarters completed; the present volume begins with Kunstharz and concludes with Natrium. It bears much the same relation to industrial chemistry that the extensive works by Mellor in English, and Abegg in German, do to inorganic and physical chemistry. The book is, however, much more than a technical encyclopaedia, for besides technical uses and processes one finds also properties of substances which have industrial use, as well described as in purely scientific monographs. The patent literature appears to be very complete, as are also the references to the literature. H. W. FOOTE.

Makers of Chemistry; by ERIC JOHN HOLMYARD. Pp. xv, 314; 98 illustrations. New York, 1931 (Oxford University Press, price $2.50).—The difficulty with the early chemists—or alchemists—as far as concerns any present general interest, is that the great majority of them were not only extraordinarily ignorant, but they appear to have usually been dishonest and secretive as well. They discovered and reported a number of facts, but the number is surprisingly small; and their vague and indefinite theories could not possibly explain the facts which they observed. It was Robert Boyle, as late as 1661, who first exposed the deficiencies of earlier chemical work and founded the modern science of chemistry. Even then, progress was delayed for the better part of a century by the phlogiston theory of Becher and Stahl. The author of this book, therefore, has a difficult task to excite the reader's interest for the men before Boyle. He has done the best he could for them in the first half of the book, but the real interest comes in the second half, when he describes the work of a succession of careful, intelligent, honest men who slowly laid the necessary groundwork on which the science of chemistry will always rest. His description of the work of these men—Black, Scheele, Cavendish, Lavoisier, Priestley, Dalton, Berzelius, and others—is excellent. A chapter on the structure of the atom brings the book to a close, as the author puts it, "on the threshold of present-day research." H. W. FOOTE.

Quanta et Chimie; by ARTHUR HAAS. Translated from the German into French by J. PERRENOT and F. ESCLANGON. Pp. 70. Paris, 1931 (Gauthier-Villars & Cie., price (paper cover) 15 francs).—The author of this small volume is a distinguished physicist, lecturer, and writer. He is at present engaged in editing the collected works of Willard Gibbs. The book—there are only four chapters—is largely taken from lectures delivered by the author to a group of physical chemists. It presents as simply, perhaps, as possible, the ideas concerning quanta which are of interest to chemists. The treatment is non-mathematical. H. W. FOOTE.

Quantitative Chemical Analysis; by FRANK CLOWES and J. BERNARD COLEMAN. 13th Edition revised by D. STOCKDALE and J. DEXTER. Pp. xiv, 605; 133 illustrations. Philadelphia, 1931 (P. Blakiston's Son and Co., price $5.75).—This book has been a standard text for forty years. The changes in the new edition are, as the authors state, confined to comparatively minor alterations and additions. It is an excellent practical book for the laboratory worker, reasonably well adapted for the beginner, but perhaps of greater service in laboratories as a general reference book, including, as it does, standard methods for a great variety of analytical determinations. H. W. FOOTE.

Nucleic Acids; by P. A. LEVENE and LAWRENCE W. BASS. Pp. 337, 14 figs. New York, 1931 (Chemical Catalog Co., Inc., $4.50). Monograph No. 56 in the series issued under the auspices of the American Chemical Society.—The scope of this monograph on Nucleic Acids by Levene and Bass is considerably wider than its title would indicate. The book is divided into two parts, the first of which consists of a series of essays on the different components of the nucleic acids; the second part describes the nucleic acids themselves. Chapter I (12 pp.) deals with those sugars that are of importance in nucleic acid chemistry, and Chapter II (5 pp.) briefly describes certain imidines, imido esters, and imidazoles. In Chapter III is given a useful and comprehensive survey of the chemistry of the natural pyrimidines, in particular their relationships to each other, their synthesis, and the methods of preparing them from nucleic acids. The purines are discussed in similar detail in Chapters IV and V.

The first 125 pages of the monograph are thus devoted to what may perhaps be called the "Bausteine" of the nucleic acids. The next 109 pages comprise two chapters on the nucleosides and nucleotides respectively; the evidence for the generally accepted view of the chemical structure of these substances is given, and descriptions of the most advantageous methods for their preparation are included. Chapter VIII briefly describes the discovery of the nucleic acids by Miescher, and the work of Kossel and his students. Chapter IX (50 pp.) contains a discussion of the evidence for the different structures that have been suggested for nucleic acid from time to time, and in particular for the formulations proposed some years ago for yeast and thymus nucleic acids by the senior author. Practical details for the preparation of nucleic acids are also given. The last two chapters describe nucleic acids of higher orders, and the nucleases.

The study of nucleic acids had its origin in investigations of the components of cells; as information accumulated the importance of these substances in the life processes of cells has become increasingly apparent. Furthermore, the discovery of allied substances in animal fluids, and in plant and animal tissue extracts, furnished evidence that nucleic acids play a part outside of the cell itself. The present state of the existing chemical knowledge of the nucleic acids is admirably outlined in the present monograph and a marked stimulation of investigation in this attractive field should result from its publication.

H. B. VICKERY.

Laboratory Exercises and Problems in General Chemistry; by B. S. Hopkins and H. A. Neville. Revised edition. Pp. xi, 164; 28 figs. New York, 1931 (D. C. Heath & Co., $1.76).—The manual is divided into three sections, the first two of which deal respectively with the chemistry of non-metals, and of metals. The third section is a short exposition of chemical arithmetic, followed by a large collection of problems, mostly numerical. The purpose of the manual is to provide an abundance of material for a course in general chemistry and to serve, if desired, as an introduction to qualitative analysis. To this end, the first section contains quite simple exercises for the beginner. About ten per cent of these exercises are quantitative in nature and are extremely well designed to illustrate a particular law or principle. In the second part, the general chemistry of metals is interspersed with a good many qualitative tests and separations, and a few pages at the end are devoted to a very brief outline of analytical procedure. By a suitable choice of experiments the student could gain an introduction to analysis, but we hope such casual acquaintance would be more fully developed in a later course.

Directions are well written, and the authors seem to have made a very happy selection of experimental material. We criticize, however, the inclusion—as laboratory experiments—of such exercises as those on Atomic Structure, Oxidation-Reduction Review, Physical Properties of Metals. As given, none of these contain any experimental material whatever. The collection of review problems will be found very useful.

Naturally, the manual is closely correlated with the "General Chemistry" of Prof. Hopkins, page references being given with each exercise. However, the manual could be adapted to many other beginning texts without difficulty. E. B. KELSEY.

Wilhelm Conrad Röntgen und die Geschichte der Röntgenstrahlen; by Otto Glasser. Pp. xi, 337, 96 figs. and portrait. Berlin, 1931 (Julius Springer, 27 Mks., 29.60 Mks., bound).—When Röntgen in 1895 observed that an excited vacuum tube which was covered with black paper caused some crystals, which lay on a table at a considerable distance from the tube, to fluoresce, he made a world-stirring discovery whose importance was at once recognized, and whose beneficence has continued to grow.

It is the aim of this book to trace the various steps in the development of the discovery, and its application to radiography, to medical diagnosis, to physics, and to industry.

It contains a most interesting account both of the experiments of Röntgen and his successors and also much detailed information touching his life and work. The photographs of the apparatus, portraits of the author, and scenes of his activities, are distinctly illuminating. It is a book of very general interest. F. E. B.

Analytical Mechanics; by H. M. DADOURIAN. 3d edition. Pp. xiv, 427, 147 figs. New York, 1931 (D. Van Nostrand Co., $4.00).—We welcome the appearance of this new edition of a first rate work on elementary mechanics, although the revision has been confined to remodelling the chapter on the Equilibrium of Flexible Cords, and the rewriting of some pages.

The unique feature of the book is that the author bases all of his discussions upon the action principle which leads to clear and explicit equations. We regret to notice that he has seen fit to omit appendix B of the second edition on Directions for Working Out Problems, which we think was too good to lose. The present writer is indebted to the author for first calling his attention to the value of the orderly setting down of the data of a problem and the systematic solution of the equations and is desirous of seeing this information transmitted to succeeding generations of students.

That the book is an excellent one we can testify from having used it as a text in the class room for several years. F. E. B.

Der Smekal-Raman Effekt; by K. W. F. KOHLRAUSCH. Pp. viii, 392; 85 figs. Berlin, 1931 (Julius Springer, 32 Mks., 33.80 Mks., bound).—In 1923, four and a half years before Raman found the result experimentally, A. Smekal had pointed out from theoretical considerations alone that when an impact occurred between a light quantum and a molecule, the light should be scattered and should, independent of its direction, suffer a change of frequency. It is for this reason that the author has coupled Smekal's name with that of Raman in the title above.

The chapter of discovery has not yet been closed, so that this book is only to be regarded as representing a stage in the development. Its aim is to serve as a memorandum and handbook for those who are occupied with Raman spectra and its contribution to the evidence for molecular structure. It will serve to give a survey over the widely scattered literature and the already great multiplicity of experiments, and show to what conclusions the data have already lead. Especially should the book be helpful to chemists whose experience and intuition are necessary in a field of work which bids fair to reach quantitative conclusions concerning the structure of the compound molecule.

The author has sought to present his subject with the least possible theoretical discussion and with the simplest mechanical pictures.

In the eight chapters of the book the experimental technique and the general properties of the scattered spectrum are well set forth, together with conclusions concerning molecular structure. Fifty pages are devoted to tables of the present known Raman spectra and a bibliography of 417 references is also given.

The book certainly appears to be a timely one.

F. E. B.

Recent Advances in Microscopy; edited by A. PINEY. Pp. v, 260, 83 figs. Philadelphia, 1931 (P. Blakiston's Sons and Co., $3.50).—This book has nothing to say of the microscope *qua* microscope and might more properly have been entitled an account of recent advances in histology. It is divided into four parts. The first by A. Piney treats of the present position of medical microscopy, or, more precisely, of microscopical anatomy, and goes into considerable detail concerning the structure of the skin, the lining of the stomach, the constituent elements of the liver and of the blood cells, and into investigations on the pituitary, the thyroid, and the adrenals.

The second section by Basil Graves is devoted to the microscopy of the living eye and shows with abundant illustrations the methods of illumination used to study the various tissues of this organ.

The third part is by E. W. MacBride and H. R. Brewer and shows various new applications of the microscope to zoology. Here the interest is centered about the activities of the Golgi apparatus, the morphology and function of the mitochondria, the phenomena of secretion, the absorption of food, and other activities of the normal cell.

The fourth and final section is by E. C. Barton-Wright and treats of a variety of subjects in botany, as, *e.g.* the structure of the chromosomes, polyploidy, cytoplasm, the microscopy of the cotton hair, etc.

As is apparent from these notes the book is of interest chiefly to the histologist. F. E. B.

GEOLOGY.

Studies of Evolution in the Genus Spirifer; by CARROLL LANE FENTON. Publications of the Wagner Free Institute of Science, Vol. II. Pp. 436; 204 text figs., 50 pls. 1931.—The paleontological record includes occasional instances of greatly accelerated evolution wherein a genus, or species, has developed unusual plasticity and burst forth into a profusion of variants. Dr. Fenton has addressed himself to the analysis of such a case of "explosive evolution" in two Devonian spirifers, *S. orestes* Hall and Whitfield and *S. hungerfordi* Hall, which occur together in great numbers throughout about 40 feet of Upper Devonian shales in the vicinity of Cerro Gordo County, Iowa. Over ten thousand specimens, collected zonally from these beds, constitute the documentary evidence in the case.

A large part of the work is taxonomic, seeking to establish the biologic units and to trace their evolution through the successive beds. The extreme views here advanced will probably be challenged by most taxonomists. Although interior shell features were not studied and it was found that neither shell form nor number of plications are reliable characters for subdivision, the

Spirifer orestes of Hall and Whitfield was subdivided into 114 named species and varieties and arranged into gentes and phratries of super-specific rank. This elaborate subdivision was based entirely on details of minute surface sculpture. It may be suggested that on such a basis the human race is divisible into 1024 species and varieties distinguished by finger print patterns, the major patterns of loops, whorls and arches characterzing species or superspecies while the subclasses of fingerprints mark varieties.

Dr. Fenton depends upon recapitulation as a means of arranging his many varieties into species, gentes and phratries and of following each through successive beds of rock. The ontogeny shown by the sculpture on different parts of an individual shell place it in the scheme. There seems to be no allowance here for individual variation, though in other characters, as shell form, variation is admittedly great. In this connection there is vital need of the study of some variable modern molluscan species in which the ontogenies of individuals raised from a single brood could be critically compared. Bartsch's study of *Cerion* on the Florida Keys does not quite meet this need but its suggests another interpretation of Dr. Fenton's material. Bartsch found that the crossing of two species, *C. incanum* and *C. viaregis,* differing from each other in shape and surface sculpture, gave an extraordinary variety of hybrid forms of which he figured 125. These hybrids differ not only in adult characters but in ontogeny as well and it is clear that the ontogenies of these shells can have no such significance as that ascribed to the Devonian Spirifers. Bartsch has suggested that cases of marked plasticity and great diversification in molluscan species has commonly been the result of such cross fertilization. It is unfortunate that Dr. Fenton did not consider this as a possible factor in the development of his highly varied Devonian shells.

Having worked out a phylogeny for all his Devonian spirifers representing their supposed evolution during the time represented by the beds from which they were collected, Dr. Fenton seeks an explanation for the changes in terms of causal theory. He concludes that the evolution was orthogenetic and had a physiologic basis in racial senescence conditioned by a decreasing metabolic rate. In this he maintains a view exactly opposed to that of Bartsch who looks upon instances of great variability and of prodigality of individuals as evidence of rejuvenescence and vigor.

From cover to cover the work bears evidence of the most painstaking care. The convincing style of presentations is matched by excellent text figures and splendid plates. Regardless of our reservations as to the taxonomy or the evolutionary theory advanced, the work is a stimulating document. C. O. DUNBAR.

Paleozoic Rocks; by WILLIAM CLIFFORD MORSE. University, Miss., 1930. Mississippi State Geological Survey Bulletin No. 23.

Pp. xi, 212; 15 text figs., 23 pls. 1930.—This welcome volume presents the first modern and systematic account of the Paleozoic rocks of Mississippi.

The outcrops of these formations are confined to the stream courses of Tishamingo County in the extreme northeast corner of the State, where eleven named formations present a composite thickness of 600 to 800 feet, representing the Devonian and Mississippian Systems. As in western Tennessee and Kentucky, the succession is much broken and thin formations represent fragments of the longer record of the Appalachian geosyncline.

With a single exception, the formational units are all given new names. It is unfortunate that the author did not extend his field studies into contiguous portions of Tennessee and Alabama where several, at least, of these formations have previously been studied and named. C. O. D.

Age of the Orbitoid-Bearing Eocene Limestone and Turitella Variata Zone of the Western Santa Ynez Range, California; by W. P. WOODRING. Trans. San Diego Soc. Nat. Hist., Vol. VI, No. 25, 1931. Pp. 371-388.—The Orbitoid limestone was formerly referred to the upper Eocene because of a stellate *Orthophragmina,* such types occurring in the Gulf province only in the upper Eocene. Field work by Bailey and Clark has shown the California bed to lie in the lower Eocene, however, and it is now accepted that the stellate type of *Orthophragmina* reached California much earlier than it did the Atlantic province.

A restudy of Conrad's original types from the *Turritella variata* zone in the Ynez range indicates that this horizon is upper Eocene. C. O. D.

The Foraminifera of the Atlantic Ocean, Pt. 8. *Rotaliidae, Amphisteginidae, Calcarinidae, Cymbaloporettidae, Globorotaliidae, Anomalinidae, Planorbulinidae, Rupertiidae and Homotremidae;* by JOSEPH A. CUSHMAN. U. S. Nat. Mus., Bull. 104, Pt. 8, 1931. Pp. 179, 26 pls.—This is the concluding part of a monograph devoted to the description and illustration of all the foraminifera known in the western Atlantic ocean from the Caribbean Sea northward. The work has required more than a decade to complete and now totals 892 pages and includes 173 plates of illustrations. Altogether, 232 genera and 945 species are illustrated and described with full bibliographic synonymies.

Many of the descriptions are accompanied by discussions of distribution, ecology and habits of life. C. O. D.

Publications of the Geological Survey of the Union of South Africa.—The following have been received:

The Geology of the North-Eastern Pretoria District and Adjoining Country; by B. V. LOMBAARD. Pp. 48, figs. Pretoria, 1931 (5 shillings, including map).—A detailed account of the geology of the area represented on Sheet 18 (Moos River) of the sectional geologic map of South Africa. The region is interesting chiefly because it is mainly underlain by the Bushveld igneous complex.

A Bibliography of South African Geology for the Years 1926 to 1930 (Inclusive). Author's Index; by A. L. HALL. Pp. 160. Memoir No. 27. Pretoria, 1931 (5 shillings).—A continuation of the bibliographies for earlier years published as Memoirs 18, 22, and 25. The entries, of which there are 2,151, are arranged alphabetically by authors. R. F. F.

Summary of Progress of the Geological Survey of Great Britain and the Museum of Practical Geology for the Year 1930. Part III, pp. x, 92, figs. and plates. London, 1931 (2 shillings).—Contains nine miscellaneous research papers by various authors, covering subjects in paleontology, stratigraphy, petrology, glacial geology, and magnetic surveying. Parts I and II have been noticed in the November number. R. F. F.

The Earth, Our Ever-Changing Planet; by CHESTER A. REEDS. Pp. iv, 120; 106 figs. and frontispiece. New York, 1931, American Museum of Natural History (The University Society, Inc.).—It often happens that a man or woman, struck perhaps by some personal observation or find, is impelled to "read up" on Geology. Between the encyclopedia, too brief and condensed for some, and the standard textbook, too long and technical for others, there has long been a gap. This space, frequently encountered by the inquiring layman, is pleasantly filled by Dr. Reeds' little book. More than a brochure, it contains a remarkably large quantity of geologic information, systematically arranged. It begins with an explanation of the immensity of geologic time and a résumé of the development of geology as a science. Following this is an account of leading theories of the origin of the Earth. The body of the book is concerned with a very concise treatment of systematic physical geology and meteorology under the heading "Atmosphere." "Hydrosphere," "Lithosphere," and "Centrosphere." Volcanoes and earthquakes are given separate treatment, and a short explanation of the significance of fossils, with a chart of geologic time, concludes the work.

The author has constantly kept in mind the character of the audience for whom he is writing. The language is simple, all complications have been avoided, and a well-selected list of further readings, arranged by special subjects, is included for the benefit of the beginner. The book as a whole ought to serve its purpose well. R. F. F.

The Geology of the Potosi and Edgehill Quadrangles; by C. L. DAKE. Pp. 233; 26 plates and 2 maps (in pocket). Missouri Bureau of Geology and Mines, H. A. Buehler, Director and State Geologist. Vol. XXIII, Second Series (Rolla, Mo., 1930).—Detailed treatment of an area on the east flank of the Ozark plateau, at the northwest border of the St. Francois Mountains. Pre-Cambrian igneous rocks are overlain by Cambrian, Ordovician, Mississippian, and Pennsylvanian sedimentaries, which dip westward away from the structural center of the Ozark dome. This regional structure is complicated by faulting and by initial dips of Cambro-Ordovician strata around porphyry knobs on the Pre-Cambrian surface. Two post-Pennsylvanian erosion surfaces are recorded by accordant summits, and streams have been superposed from these surfaces across porphyry knobs.

The economic products of the district are barite and lead, the occurrences of which are discussed. R. F. F.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Handbook of Ethnography; by JAMES G. LEYBURN. Pp. vii, 323; and maps. New Haven, 1931 (Yale University Press, $5.00).—Ethnologists and other students of social science must often have felt the necessity of a convenient handbook which would enable them to locate the numerous tribes and geographical terms which they come across in their reading. A specialist, working in a narrow field, is not likely to profit much from such assistance, but the student who ventures to stray any distance from his more strictly localized field of research is soon lost in the maze of names and doubtful identifications of peoples who bear more than one name, either in fact or in the literature of anthropology. Professor Leyburn deserves the cordial thanks of all such students for undertaking the exceedingly laborious task of compiling this handbook.

The book is a neat and compact work of 323 excellently printed pages, supplemented by six very useful maps. The body of the work consists of two parts, an "Alphabetical List of the more important Peoples of the World, together with their Location, and a Comment on Geographical Terms commonly used in Ethnography" and a "Table of Peoples arranged under the Political Divisions of the World."

For restricted areas there are, of course, more extensive and informative books of reference, such as the two volumes published by the Bureau of American Ethnology under the title of "Handbook of American Indians North of Mexico," but the reviewer knows of no other work which so successfully compresses within the covers of a moderately sized volume as much information on ethnographic nomenclature. The book will probably soon prove to be a *sine qua non* of the comparative anthropologist, whatever may prove to be its incidental inaccuracies of detail.

It would be folly to expect anything like one hundred per cent accuracy in an undertaking of this kind and it would be even greater folly for a reviewer to attempt to pass on the general accuracy of the whole work. It is made sufficiently clear in the preface that the compiler lays no claim to accuracy, completeness, or scrupulous consistency. No doubt, as the book gets tested by use and comment, a number of easily corrected shortcomings will reveal themselves, and it is to be earnestly hoped that the present volume may prove to be merely the first edition of a work which will come to be looked upon as the authoritative book of tribal reference.

If the reviewer ventures to make a few critical comments on specific entries in the volume, it is not, he likes to think, because of a childish desire to pick flaws in an obviously useful undertaking, but rather because he hopes that such comments may point the way to a second and still more useful edition of the Handbook.

In the "Table of Peoples" which forms the second part of the book it would have been exceedingly useful to distinguish between names referring to present peoples and those which are quoted from classical and other historic sources and which, in many instances, refer to peoples no longer existing as such. Under Portugal, for instance, are listed Iberians and Portuguese without any indication that the former is a classical term not applying to an actually existing people. The necessary information can be secured by referring back to the entries in the "Alphabetical List" but a different style of printing for the extinct peoples would undoubtedly be a help to the student. Under Russia a somewhat disproportionate number of the entries refer to the Caucasus, and for this reason it might have been advisable to enter these peoples under a special heading.

The first problem that any compiler has to solve in planning a work of this sort is what principle to adopt in the choice of his main entry for a particular tribe or people. There is often a great variety of spellings of the same name and, not infrequently, a number of quite distinct names referring to the same group. Shall he adopt the rule of priority of term and spelling or shall he adopt the name which seems to be vouched for by the most recent and authoritative literature that he can find? Now and then he may decide in favor of a spelling that has become more or less popular, but it is not often that common usage will be able to help him. Whatever principle he adopts, he will find himself in conflict with the personal choices of other anthropologists. The reviewer's preference is for those spellings which have the backing of the most important authority or authorities on the people in question, but he admits that there is room for considerable difference of opinion in applying the principle. His personal reference, for instance, would have been for Tlingit rather than for Tlinkit (p. 242). Prof. Leyburn's entry has good authority, but Swanton, who is our latest authority on this people, speaks of the Tlingit and, inasmuch as current American anthropological usage has tended to prefer Swanton's spelling, that should perhaps have been chosen. Another and clearer case is that of the Chimalakwe (p. 59), a name used by Powers in his "Tribes of California" but entirely superseded now among American anthropologists by Chimariko. On the whole, however, it is the reviewer's impression that Prof. Leyburn has made the choices which would commend themselves to the majority of ethnologists.

More important is the question of whether all entries of significance have been made. It is in the geographical part of the work that inconsistences seem to be most in evidence. Aargau (p. 1) is listed as a canton of Switzerland but such other cantons as Uri, Schwyz, Unterwalden, Grisons and Lucerne are not included. It would seem that the principle here should be all or nothing. As to the tribal entries, such superficial testing as the reviewer has been able to give the work indicates that there are few important oversights. He offers for supplementary inclusion Alarodian, the people of the region of Lake Van, who preceded the present Armenians; Tokharian, a Buddhist people of Chinese Turkestan whom recent investigations have shown to have spoken the easternmost known Indo-European language that we have record of in early times; and Yenisei-Ostyak, a people not to be confused with the Ugro-Finnic Ostyak but speaking an entirely distinct and fundamentally unrelated language.

A further point of importance is the adequacy and correctness of the cross-referencing. Here again Prof. Leyburn seems, in the great majority of instances, to have been as accurate as one can be in such matters. A few slips, or what seem to the reviewer to have been such, may, however, be noted. The entry Aht (p. 6) should cross-reference to Nootka (p. 178). The two tribes, or rather groups of tribes, are identical but there is nothing in the handbook to show this. The same applies to Wiyot and Wishosk (p. 266). There is nothing to show that Minitaree (p. 160) refers to the same tribe as Hidatsa (p. 9). Again, the entries Mije and Mixes are somewhat misleading because they are given as located in slightly different parts of Mexico, whereas they are really the same people. Lepan is, of course, identical with Lipan (p. 134), though this is not clear from the entries. It is the reviewer's impression that the work would gain vastly in authoritativeness if it were tidied up on points of this sort.

Of downright errors, or disturbingly misleading statements, the reviewer has found remarkably few. A few comments may be ventured. Rikwa (p. 207) is not a tribe at all but merely a village of the Yurok. A complete enumeration of American Indian and other primitive villages would, of course, increase the scope of the work more than tenfold and there seems no adequate reason for this particular entry. Tusayan (p. 249), if the reviewer is not mistaken, is not properly a synonym of Hopi, but an old name for the country that they inhabit. Quapaw (p. 204) is described as "a S W Siouan tribe, forming one of the two divisions of the Dhegiha group." This does not quite square with the entry Omaha. The entry Fulbe (p. 85), explained as "the Mandingo name for the Fulah," is not quite satisfactory, for this form of the name is, as a matter of fact, the proper plural form of the tribal name as used by the people themselves, the corresponding singular being Pulo (p. 202).

These random strictures merely prove that the Handbook can be improved. The important thing is that the Handbook, though improvable, is a welcome and indispensable aid to the ethnographer.

EDWARD SAPIR.

The Birds of Massachusetts and other New England States; by EDWARD HOWE FORBUSH.—This great work is published by the Commonwealth of Massachusetts, Arthur W. Gilbert, Commissioner. It consists of three quarto volumes (price $5 each) with 93 colored plates. Volume I, first issued in 1925, embraces all water birds, ducks, geese, marsh and shore birds. Volume II (1927) includes game birds, birds of prey and perching birds, with the grackles. Volume III has been recently issued (1929); it embraces the song birds—sparrows, thrushes, warblers—and the many other familiar birds. The work as a whole is a fitting monument to the author, Mr. Edward H. Forbush, whose life was cut off March 9, 1929, when the third volume was nearly completed. His successor, as state ornithologist, Dr. John B. May, has edited this last volume. He also gives a most interesting account of Mr. Forbush (pp. xvii-xlviii, with portrait); this should be read by all interested in the bird life of the country.

Volume III contains 466 pages, with 31 beautiful colored plates (Nos. 63-93); 30 figures, reproduced from excellent photographs (chiefly by Miss Cordelia J. Stanwood), these are also printed as plates. In addition there are in the text 23 figures and 17 maps, the latter giving the distribution as to season of important species. It would be difficult to say too much in praise of these three volumes which the world owes to Mr. Forbush and the State which gave him its support. The descriptions of the life and habits, and other details of each bird are given as only so skilled an observer could know them. The colored plates are also most remarkable in the drawing of each bird, the accuracy and delicacy of the coloring, and the grouping and setting as a whole. Nothing could be more perfect, for example, than the bluebirds and robins on plate 93. These plates are reproduced from the fine paintings of the late Louis Agassiz Fuentes[1] and Major Allan Brooks. This third volume will be especially appreciated by all bird lovers since it gives to them the species they know best.

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[1] This Journal, Vol. 14, 331, 1927.

Travaux de la Section de Géodésie de l'Union Géodésique et Géophysique Internationale. Tome 7. Published by the Secretary, GEORGES PERRIER. Paris, 1930 (78 Rue d'Anjou, 8e).—This important volume contains reports of the work accomplished in the fifteen countries enumerated below, and presented at the Fourth General Meeting of the Union in Stockholm, August 11 to 23, 1930. The countries here represented are: Argentina, Belgium and Belgian Congo, Denmark, Equador, United States, France, Greece, Hungary, Italy, Norway, Roumania, Switzerland, Czechoslovakia, Union of South Africa, and Yugoslavia. The second part of volume seven will contain reports from Canada, Egypt, Spain, Finland, Great Britain, India, French Indo-China, Japan, Mexico, Netherlands, Poland, Portugal, and Siam.

The subjects discussed in volume 7, include determinations of gravity; triangulations, in part local, or broader bearing upon the figure of the earth; also local leveling. Further, the report from Greece includes an account of the eruption of the volcano of Santorin in 1928. The eruptions in 1925-26 were discussed in the report of the third assembly.

It is impracticable to give a summary of the valuable and varied results which are given in this large volume. Some appreciation, however, of the magnitude of the work, and hence of the value of this International Union, will be given by the statement that this volume contains the papers from the 15 countries named, which are discussed at length on upward of four hundred pages of text and illustrated by sixty-three plates and maps.

BULLETIN No. 8. *Section of Magnetism and Terrestrial Magnetism.* Comptes Rendus de l'Assemblée de Stockholm, August 15-23, 1930. Publiés par les soins de Ch. Maurain. Paris, 1931 (49 Bd. Saint Michel). Pp. x, 479, with figures and maps; also as the frontispiece, a portrait of Charles Chree, the former president (1860-1928).—The many interesting papers and reports in this volume, from the different countries, add much to the knowledge of the world's terrestrial magnetism.

BULLETIN *Géodésique.* No. 29. January-February-March, 1931. Pp. 84. Paris (J. Hermann).—This Bulletin contains seven scientific papers, also biographical notices of Alfred-Ernest Young (Great Britain), Frederico Guarducci (Italy), and Raoul Gautier (Switzerland).

Annual Report of the Director of the Coast and Geodetic Survey to the Secretary of Commerce for the fiscal year ended June 30, 1931.[1]—This, the 100th Annual Report of the U. S. Coast and Geodetic Survey, marks the completion of more than a century of its active service. The work of the Survey began in 1816 when

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[1] Copies of this report can be secured from the Director, Coast and Geodetic Survey, Washington, D. C. Or New York Field Station, Coast and Geodetic Survey, Room 328, No. 6 State Street, New York City.

Dr. Ferdinand Rudolf Hassler was appointed superintendent; and the Centennial Celebration was held one hundred years later in April, 1916.[2] Hassler's program was remarkable for the breadth and accuracy of its conception at a time when such work was relatively in its infancy. His plan included the Survey of the entire coast, in detachments to be finally united by geodetic control.

The high standard set for the Survey at the beginning has been carried on up to the present time; this is made possible by the steady development of science. For example, the important sea-soundings can now be made from a rapidly moving vessel and out of sight of land and thus the exact contour of the ocean bottom can be fixed. In this work, the times of the sound of a bomb explosion in the water at the nearby ship, on the bottom, and at two fixed shore stations are noted. These are given by delicate instruments, using the radio, which make possible the determination of the respective times, and hence the depths and the distances involved. Again, increased care is used in tidal observations, especially as affected by local conditions.

As regards the future, it is to be noted that an expanded Geodetic Survey program has been inaugurated (1931) to be completed in some 15 years. This can now be pushed forward at an accelerated rate and hence with reduced expense. Also, the increasing call for accurate airway maps is to be met by a series of 92 sectional maps, in color, to cover the entire country; three of these have already been issued.

PUBLICATIONS RECENTLY RECEIVED.

Beretninger Fra Chr. Michelsens Institutt for Videnskap og Andsfrihet. Bind I. Bergen, 1931 (A. S. John Griegs Boktrykkeri).

Molecular Rays; by Ronald G. J. Fraser. New York, 1931 (The Macmillan Company, $3.75. Cambridge, at the University Press, 1931).

The Microscopic Characters of Artificial Inorganic Solid Substances or Artificial Minerals; by Alexander N. Winchell. With A Chapter on the Universal Stage; by Richard C. Emmons. Second Edition. New York, 1931 (John Wiley & Sons, $5.00).

Natural Gas in Western Kentucky; Willard R. Jillson. The Kentucky Geological Survey. Series ix, Volume thirty-eight. Price $1.25. Frankfort, 1931.

Mass, Zahl und Gewicht in der Chemie der Vergangenheit; von Paul Walden. Sammlung chemischer u. chem. -techn. Vorträge, heraussgegeben. von H. Grossmann, Berlin. Stuttgart, 1931 (Verlag Ferdinand Enke, 10 Mks.).

Ohio State University Studies. The Engineering Experiment Station. Bulletin No. 59. Utilization of Pebbly Clays for Heavy Clay Products Manufacture; by Fred T. Heath. (Price fifty cents.)—Bulletin No. 62. Belt Drives with Cast-Iron Pulleys and Paper Pulleys; by C. A. Norman and G. N. Moffat. (Price twenty-five cents.)—Bulletin No. 64. Relative Heat Transfer Through Refractories; by A. S. Watts and R. M. King. (Price fifty cents.) Columbus, 1931.

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[2] See this Journal, vol. 42, p. 505, 1916.

OBITUARY.

DR. DANIEL DRAPER, for forty-two years the distinguished meteorologist of New York City, died on December 21, at the age of ninety years. His early studies in meteorology and astronomy, as also in chemistry and physiology, were carried on under the guidance of his father, Dr. John William Draper (1811-1882, see this Journal, vol. 23, 163, 1882). The Meteorological Observatory in Central Park was established by Dr. Daniel Draper as early as December 28, 1868. From there, hourly weather observations were sent out by him for many years. To him the world owes also the invention of a long series of scientific instruments essential in the varied observations involved in determining and recording the weather.

DR. JOHAN AUGUST UDDEN, director of the department of economic geology at the University of Texas, died on January 5, at the age of seventy-two years. Born in Lekasa, Sweden, he came to Carver, Minn., in 1861, and he was graduated at Augustana College at Rock Island, Ill. He was long identified with the bureau of geology at the University and had the credit of discovering oil in several locations in Texas, including wells on University lands; also of discovering potash in the Texas Permian basin. He also served as special assistant to the Iowa Geological Survey from 1899 to 1903, was geologist for the Illinois Geological Survey from 1906 to 1911, and special agent for the United States Geological Survey from 1908 to 1914. He was knighted by the King of Sweden in 1911.

DR. JOHANNES PAULUS LOTSY, professor of botany at the University of Leyden, died last November at the age of sixty-four years. His botanical work began in the East Indies in 1896. It was carried on actively in various important lines till his retirement six years ago. Since then he has worked in New Zealand and South Africa devoting himself especially to the subject of evolution.

DR. HUGO DE BÖCKH, the Hungarian mineralogist and geologist, died recently at the age of fifty-seven years.

PROFESSOR JOHAN KIAER, well known stratigrapher, paleontologist, and museum director at Oslo University, Norway, died at Oslo suddenly on October 31. He will always be remembered for his detailed work on the later Ordovician and Silurian stratigraphy, and for his excellent reconstructions of the late Silurian and early Devonian fishes.

DR. CARVETH READ, professor of philosophy and later of comparative psychology at the University of London, died on December 6 at the age of eighty-three years.

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RADIOACTIVITY AND THEORIZING

BAILEY WILLIS

ABSTRACT.

Since 1915 several geologists and geophysicists have framed hypotheses regarding the distribution of radioactive minerals in the earth and the heat-effects attributable to them. Holmes, Joly, Chamberlin, Barrel, and L. H. Adams have published more or less elaborate discussions. In this article the several hypotheses are considered from the point of view of the method of multiple hypotheses, each of them being briefed and subjected to the test of the verity of its fundamental assumptions. The task is simplified by grouping the theories under two heads, namely those that postulate some regular distribution of radioactive minerals in the globe versus those that assume irregularity of distribution. Reasons are assigned for regarding the former as inconsistent with the facts and consequently unreal, whereas the latter group of discussions appears to contain the seed of fruitful progress toward an understanding of the thermal, eruptive history of the earth.

INTRODUCTION.

The investigation of radioactive minerals, from the initial discovery by Becquerel in 1896 on to the suggestion of Rutherford in 1905: "the present rate of loss of heat of the earth might have continued unchanged for long periods of time in consequence of the supply of heat from radioactive matter in the earth," furnished geologists with a source of energy previously unknown and has led to the evolution of a group of theories based upon assumptions regarding the work that energy may have performed or be performing. At the end of twenty-five years the divergence of opinion ranges from the agnosticism of the veteran geochemist, F. W. Clark, and the petrologist, N. L. Bowen, to the elaborate theories of geothermal history by Joly and Holmes. The subject has not, however, received very general consideration outside of the group of English geophysicists, as Holmes in his latest paper with reason observes, and it seems not inappropriate to review the more important contributions from the point of view of dynamical geology. There is the more reason for so doing because the theories put forward in the name of radioactivity require revolutionary changes in our concepts of geologic

Am. Jour. Sc.—Fifth Series, Vol. XXIII, No. 135, March, 1932.

history. Furthermore, however doubtful the validity of any particular theory may be, radioactivity is a fact and it cannot be ignored. The very uncertainty that in our ignorance attends any consideration of its working invites us to proceed by the method of multiple hypotheses, so fruitfully applied by Chamberlin and Gilbert in exploring the unknown.

AMOUNT AND DISTRIBUTION OF RADIO-ELEMENTS

The initial suggestion by Rutherford[1] led Strutt[2] to analyse certain available specimens of rocks with reference to their radium content. Strutt's results comprised 28 analyses. The investigations were continued by various workers until, in 1914, Holmes was able to cite 318 analyses, which he regarded as representative and which he grouped according to the types of rocks.[3] Inasmuch as Joly had used a method of analysis which gave somewhat higher results than those observed by anyone else Holmes tabulates them separately. The averages are as follows:

Radium per gram of igneous rocks in billionths*
(10^{-12}) of a gram.

	H. and others		Joly		All	
Acid rocks	41	2.51	86	3.01	127	2.84
Intermediate rocks	70	1.74	48	2.57	118	2.08
Basic rocks	28	0.66	31	1.28	59	0.98
Ultra basic rocks	14	0.50			14	0.50

N. B. The number in the first column in each group gives the number of specimens analysed.

* English usage, i.e. million millionths.

Additional determinations of radium in rocks have more recently been made by Ellsworth of the Canadian Geological Survey[4] and by Pigott of the Geophysical Laboratory, Washington.[5]

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[1] Rutherford, E., Radio-Activity, 2d ed., 1905, p. 496.

[2] Strutt, R. J., Radium in the Earth's Crust, etc., Proc. Roy. Soc., series A, 77, 472-485, 1906.

[3] Holmes, Arthur, The Terrestrial Distribution of Radium, Science Progress, 9, 15, 1914-15.

[4] Ellsworth, H. V., Radium-bearing Pegmatites of Ontario, Geological Survey of Canada, Summary Report, 1921; Part D, 51-70, 1922.

[5] Pigott, Chas. S., Radium Content in Representative Granites of the Eastern Seaboard of the United States, this Journal, 17, 13-34, 1929; and Radium in Rocks II. Granites of Eastern North America from Georgia to Greenland, op. cit. 21, 28-36, 1931.

Ellsworth's work was directed specifically to the economic purpose of ascertaining the distribution of radium-bearing minerals with a view to their exploitation as ores of radium. His results therefore have no direct bearing upon the average distribution of radium, except as they serve to call attention to the concentration of radium in pegmatites, which are themselves special segregations from the much larger masses of granite.

Pigott, on the other hand, sought to determine the amount of radium in average specimens of granite and in as many granites as could conveniently be secured from the batholiths of eastern North America. He analysed 18 granites. Excluding two, he obtained in the remaining 16 a range from 0.26 to 2.79 grams x 10^{-12} of radium per gram of rock and an average of 0.897 gram x 10^{-12}. The two samples which were excluded because of their richness in radioactive minerals were from Stone Mountain, Georgia, and North Jay, Maine. They contained respectively 3.81 and 3.39 x 10^{-12} gram of radium per gram of rock.

Pigott's average of 0.897 for 16 granites of the Appalachian province may be contrasted with the average for acid rocks obtained by Holmes and others, 2.51, and with Joly's figure of 3.01. Examination of the data from which the last two are derived indicates that there is a wide range in the radioactive content of specimens of granite analyzed, from 0.55 to 6.00; and it would appear that this may be due to a generally low content in the rocks of a particular province or to exceptional richness or poverty of the individual specimens. In a succeeding paragraph attention is called to the possibility of secondary enrichment or impoverishment in radioactive minerals.

In connection with problems of petrogenesis it has been held that the acid rocks are richer than basic rocks in radioactive minerals. There can be no doubt of the association of such minerals with pegmatites; but since the latter are special segregations they cannot be cited as representing average granites. Pigott's samples were selected to represent average granites of the Appalachian region, and his average of 0.897 for those acid rocks is very close to the figure of 0.98 for basic rocks, as shown in the preceding table. Doubt is thus thrown upon the inference that acid rocks, excluding pegmatites, have as a rule a higher content of radioactive minerals.

The available evidence regarding the amount and distribution of radioactive minerals in the accessible rocks of the earth's crust is thus to the effect that: (1) they are present in exceeding minute quantities only; (2) there is a very wide range between the relatively rich and the relatively poor rocks; and (3) the analyses thus far made fail to indicate conclusively any specific, constant, or regular association of radium with either of the major classes of igneous rocks: acid or basic.

If, nevertheless, we were to accept the results of analyses to date as the basis of an estimate of the amount of radioactive minerals in the accessible rocks, we would conclude that about 1 billionth (10^{-12}) of a gram of radium per gram of rock would be the proper figure. The assumption that we may so accept the results with any confidence is, however, open to grave doubt. The available evidence as to how the specimens were selected fails to distinguish between random samples, average samples, or picked samples. Whatever may be assumed on this point the uncertainty remains.

It would be desirable to know the antecedents of every rock that has been or may be examined for its radioactive content, at least with the degree of detail that would be required were the occurrence that of any ore upon which investments were to be made—copper, for instance. In such a case it would not suffice to know merely the lithologic association of the ore, as with granite or basalt; the intimate mineralogical association and the sequence of mineralization would be determined. The primary or secondary origin of the copper, i.e. radioactive mineral would be sought out. If it were primary and occurred in a granite batholith its association with the more or less volatile or hydrothermal constituents—pegmatites, for example—would lead to inferences regarding the enrichment of the higher portions of the granite mass, those nearer the cover. If, on the other hand, the ore were secondary in origin any unusual richness would lead to suspicion of secondary enrichment by downward percolating waters, and the physiographic history of the deposit would demand consideration.

As an illustration we may consider the abnormal richness of the Stone Mountain, Georgia, granite, which contains about four times as much radium as the average of Appalachian granites.[6] As described by Watson,[7] Stone Mountain is the central portion of a larger granite mass that is distinguished from the outer and lower lying portions of the same granite by the presence of tourmaline, which does not occur with the same abundance in them. Watson dismisses the idea that the tourmaline was an original constituent mineral of the magma, and concludes:

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[6] Pigott, Chas. S., Radium in Rocks, II, this Journal, **17**, 26, 1929, and **21**, 35, 1931.

[7] Watson, Th. L., On the Occurrence of Aplite, Pegmatite, and Tourmaline Bunches in the Stone Mountain Granite, Jour. of Geol., **10**, 186-193, 1902.

> "The very nature of the areas" (in which it is concentrated) "opposes the hypothesis, of direct secretion out of the eruptive granite magma. On the other hand, the characteristic mode of occurrence and intimate relationship to certain other mineral species present . . . make it reasonably certain that the tourmaline areas have resulted from fumaroles highly charged with boric acid acting on the feldspars and mica."

From this it would appear that the central mass in which tourmaline formed was subject to pneumatolitic agencies which produced local concentrations. Pigott notes that uranophane, which according to an analysis by Packard contained from 47.18 to 61.28 per cent of uranium oxide, was always found near relatively large accumulations of black tourmaline crystals. Thus from this association we might infer that the uranophane was a pneumatolitic concentration, deposited at a later stage than that of the formation of the tourmaline, since it occurs crystallized on the surfaces of point planes and crevices.

A somewhat different surmise may be based upon the fact that Pigott found that the radioactive substance would be partly removed by leaching during the brief soaking and washing incident to the laboratory treatment. This being so, the downward percolating atmospheric waters to which the mountain has been exposed during geologic ages must have effected some transfer of the minerals from higher to lower levels. Stone Mountain is a massive island-mount, a chemically resistant monadnock rising 636 feet above the Tertiary peneplain that is cut upon the surrounding gneisses. It itself has been exposed by erosion of still higher portions of the granite, which may presumably have contained radioactive minerals. These may have been leached out during the process of decay and erosion and have been redeposited as secondary enrichments in the mass that remains. The phenomenon is a familiar one in copper deposits and produces remarkable concentrations.

That uranophane does occur as a secondary mineral appears from the following description of deposits at Silver Hill, near Lusk, Wyoming:[8]

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[8] Larsen, E. S., et al., Uranium Minerals from Lusk, Wyoming; Am. Min., 11, 155-168, 1926.

> "At Lusk . . . silver and copper had been mined in a small way . . . . The primary minerals present are chalcocite and pitchblende . . . . Secondary minerals present are: azurite, malachite, chrysocolla, uranophane, partly in radiating tufts of tiny crystals, and a red mineral . . . not tested."

It is not proposed here to argue whether the radioactive minerals of Stone Mountain were concentrated by pneumatolitic or by atmospheric agencies. The purpose is merely to bring out the fact that the determinations of radioactive content are of no value as a basis for theorizing unless the geologic conditions governing their formation are determined by intimate studies of the original deposit. This point has not been adequately considered in the estimates of radioactive elements.

The thermal condition of the earth, as it now is or as it was at any time in the past, is, however, not directly related to the amount of radioactive minerals in the *outer crust*. Even if we omit consideration of all other possible sources of heat, as is done in theorizing regarding the effect of radium, we need to know the proportion of radioactive minerals in the *body of the earth*. Of the state of our knowledge on that point there are two distinct views, as appears from the following quotations:

> "An attempt to compute the total amount of radioactive matter in the earth and its thermal significance would be obviously premature. The available data are too scanty, too discordant, and in some respects too incomplete for such a purpose."[9]
>
> "Although numerically the actual proportion of the radio-elements in the rocks is exceedingly small, yet owing to the fact that their disintegration is accompanied by a spontaneous generation of heat, it happens that their presence is fraught with a significance that cannot be over-emphasized. If each gram of the earth's substance were as rich in radio-elements as are the rocks which have been examined, the earth's total output of heat from this source alone would, in any given period, be about 300 times as great as the amount actually lost by conduction to the surface and radiation into space."[10]

The thermal theories which have since been developed by Holmes and Joly spring from the concepts originally expressed by Holmes in this passage. The concepts are so fundamental to that theorizing that we may well state them distinctly. They are: (1) Heat is generated by radioactive elements in every gram of the earth's substance; and (2) Any heat generated in excess of that which can escape by conduction must raise the temperature of the interior of the earth.

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[9] Clark, F. W., The Data of Geochemistry, U. S. G. S. Bull. 616, 316, 1916.

[10] Holmes, Arthur, Radio-Activity and the Earth's Thermal History, Geol. Mag., Decade 6, 2, 60-71 and 102-112, 1915. Page 61.

If it be assumed that heat is generated in some, but not in each and every gram of the earth's substance, or that heat may be used up in work performed within the earth, or that heat may escape by any other process than by conduction, then quite different theories of the thermal history would result.

In attempting to assemble some of the many hypotheses which these alternatives present, we may well group them according to major postulates, among which assumptions regarding the distribution of radioactive elements in the earth appear to be most distinctive.

GROUP I.

Hypotheses based on the assumption that radioactive elements are distributed in the earth in some regular manner.

(a) Holmes, 1915: radio-elements largely confined to an outer crust.

(b) Joly, 1925: radio-elements concentrated in an outer crust, but also distributed in the substratum in such minor proportion that the heat generated may melt the substratum yet also permit it to resolidify.

(c) Holmes, 1928-29: radio-elements concentrated in an outer crust, but also distributed throughout the substratum to a depth of 2900 km. in such proportion that they maintain a condition approaching that of fusion and devoid of strength, a condition consistent with the formation and continued activity of convection currents in the substratum.

Holmes, 1915.

The first discussion of the earth's thermal history as deduced from an estimate of the radioactive heat was published by Holmes in 1915.[11] He assumed

(a) The earth is a cooling spheroid, which has been cooling during 1,600,000,000 years. There has always been a minimum depth of possible rock fusion, which has varied during the earth's geologic history. The depth has been slowly increasing and has now reached some considerable, but indeterminate depth, although at the beginning of geologic history it may have been at or immediately below the then existing surface.

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[11] Op. cit.

(b) It is not reasonable to assume that our planet is getting hotter.

(c) Yet, "If each gram of the earth's substance were as rich in the radio-elements as are the rocks which have been examined, the earth's total output of heat from this source alone would, in any given period, be about 300 times as great as the amount actually lost by conduction to the surface and radiation into space."

Hence it would follow that the earth must be getting hotter unless: 1. "The radioactive elements are largely confined to the crustal rocks" or, 2. "the disintegration to which the heat owes its origin may be inhibited under conditions prevailing in the earth's interior." The latter condition (2) appears to be excluded by experimental results.

(d) There is a "density stratification of the earth comprising a core" . . . and . . . "a thick peripheral shell . . . . which becomes increasingly acid and alkaline as the crust is reached." This hypothetical stratification is consistent with the assumption that radioactive elements are concentrated in an outer shell, since they occur most abundantly in silicious and alkaline rocks.

(e) The total amount of heat lost from the earth by conduction and radiation is exactly made good by radiothermal action.

(f) "Taking the simplest possible distribution of the radioactive elements" it is assumed "that the average content of the surface rocks is uniformly maintained down to the maximum possible depth consistent with the limited heat production allowed it."

In order to calculate the depth of radioactive rocks it is further assumed that

(g) "The total amount of heat lost by the earth" by conduction and radiation may be calculated by means of a formula which involves the area of the earth's surface, the average conductivity of rocks, and the average temperature gradient near the surface of the continents.

The conductivity of granite (which is 3/2 that of basalt) having been taken for continental areas, the further assumption is made that the heat lost per unit area of suboceanic rocks is equal to the corresponding amount for continental rocks. From this calculation the total amount of heat lost is found to be 9.71 billion calories per second. In a footnote the author argues that this is not an overestimate because: (1) the thermal gradients are under rather than overestimated, and (2) "the heat lost from the earth by igneous activity is not included."[12]

The next step in the development of this particular theory was to calculate the output of heat per cubic centimeter, due to radioactivity, and thus to find the depth of the radioactive layer that would produce as much heat as is lost by conduction. By postulate the occurrence of radioactive elements could not extend to a greater depth.

For details of the calculation the reader is referred to the original article. It must suffice here to quote the essential conclusions in so far as they have not already been anticipated.

> "Thermal considerations demand that the radioactive elements should be confined almost altogether to an outer shell of the lithosphere.
>
> Volcanic temperatures indicate that the density of distribution of the radioactive elements falls off rapidly with depth, the rate of decrease being perhaps greater under the continents than under the oceans.
>
> For mathematical purposes radioactivity and heat generation are assumed to decrease exponentially in depth, this being a law of decrease which can be adapted to agree with the limiting conditions of rock distribution (superficially and in depth) and volcanic temperatures."

In the second part of this paper of 1915 Holmes extended the discussion of the theory he had elaborated to its application to problems of the earth's internal heat, the age of the earth, and the rate of cooling as retarded by radio-heating. In later researches on the subject (from 1925 on) he has, however, courageously abandoned that thesis as inconsistent with the facts and with the course of geologic history.

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[12] Regarding this last item Professor Holmes writes that in 1915 he considered its effect in causing loss of heat "to have been great at certain periods, but at others (far longer) almost negligible." Now he regards it "—particularly in the formation of new ocean basins—as a dominant method of getting rid of excess heat." Personal correspondence, September, 1931.

Joly, 1925.[13]

The Surface History of the Earth is a difficult book to analyse because it is written to be read not only by fellow scientists of the author, but also by those who must take its statements of fact and inference on faith, uncritically. The assumptions have, therefore, to be untangled from the argument. Since they are not explicit they may be overlooked or misunderstood. The essentials are, however, clear.

Chapter I describes surface structure and emphasizes the idea of the general occurrence of basalt under the continents and ocean basins.

Chapter II discusses isostasy, which is assumed to be a state of equilibrium that is maintained by the buoyant flotation of lighter (granitic) masses in a denser (basaltic) substratum.

Chapter III treats of the continents and the substratum. The average density of the former is taken as 2.67 and that of the latter as 3.0. On geodetic evidence the "emergent part" of the continents is found to be 3.22 km. and, the co-efficient of buoyancy being taken as 8, the submerged depth or draft is found to be about 26 kilometers. The sum of 3.22 + 26 or 30 kilometers gives the thickness of the continental (granitic) layer. That this is not uniform is evident on comparing the unequal mean elevations of the continents and their major divisions.

The condition of buoyant flotation thus postulated is assumed to exist in case solid granite floats in solid basalt. If the basalt is molten or should be melted the liquid basalt would be less dense and the granite would sink deeper. Calculations based on experimental data indicate that the change in specific gravity of the basalt would result in continental subsidences comparable in magnitude with the depths of epeiric seas. The present state of the basalt is presumed to be solid.

These considerations lead to an examination of radioactivity as a source of heat.

It is assumed that the interior of the earth and an outer shell are independently heated, both by radioactive energy, but the outer shell in higher degree.

The heat of the outer shell escapes by conduction to the surface. No other mode of escape or exhaustion is considered.

If the radioactive heat of the outer shell does not exceed that which can escape by conduction there will be no surplus. If heat is generated in excess of that which can escape by conduction upward it must flow downward into the subcrustal layer.

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[13] Joly, John, The Surface History of the Earth, 1925, also Radioactivity and Earth's Surface, The Observatory, 49, 53-56, 1926.

Assuming that the *average* radioactive content of granitic rocks has been determined with sufficient accuracy, that figure is used to calculate the temperature at the base of the continental layer (30 km. below the mean continental surface). It is found to be in the neighborhood of 1000 C, i.e. near but below the melting point of basalt at the surface. The foundation of the continents is, therefore, apparently solid at the present time, but would melt if an excess of radioactive heat flowed downward from the continental shell. Any excess of radioactivity in the outer shell, over that which could be taken care of by conduction to the surface, would be used up in raising the temperature or contributing to the latent heat of the underlying basalt.

The basaltic shell is assumed to be radioactive also, though in minor degree. Assuming that it extends beneath the ocean waters without a granite blanket, it will lose heat to them by conduction through an outer shell of its own material, but that shell will have a limited thickness (48 km.) and will itself blanket the underlying basalt of the interior. Since heat is being generated continuously beneath the blanket and cannot escape, the temperature of the deeper basalt must rise and it must eventually melt.

Thus melting is an eventual condition beneath both continents and oceans; that is, everywhere in the subcrustal, basaltic shell.

A molten phase of the basaltic substratum is regarded as a cause of continental subsidence, as already stated.

In order that the molten phase should not be indefinitely prolonged some mode of escape must be found for the accumulated heat. Escape through the continental granitic shells is excluded from consideration, except in a minor degree which might lead to regelation of the basalt beneath them (p. 95). Therefore it is through the ocean floor that an outlet must be found. It is assumed that the floor would be attacked and melted from below upward by superheated convection currents in the molten basalt, and that it would thus be reduced in thickness from 48 km. to possibly 6 km. (p. 97), the limiting thickness being fixed by the rate of conduction through the thin blanket remaining.

The limiting thickness of the ocean floors being reached, molten basalt in contact with their lower surface would chill, solidify, and sink in its own magma. It would thus rebuild the solid basalt shell from below upward.

In order that that considerable part of the basalt which is blanketed by the continents may also congeal it is postulated that tidal stresses cause the continents to drift westward as they float in the liquid basalt, and thus to uncover the magma, which solidifies.

The melting and refrigeration of the basaltic shell constitute the events of a "revolution," and a comparison is established between the thermal data and the rhythms of geologic history more or less generally recognized by geologists.

This analytical review covers the first 104 pages only of the book, the latter half of which deals with the application of the theory to geologic speculations regarding the origin of mountains, the age of the earth, and related problems.

The outstanding feature of the theory is the deduction that thermal cycles have characterized the history of the earth. The heat generated by radioactive elements has, according to theory, alternately accumulated in the substratum and escaped by conduction through the suboceanic crust, with a rhythmic series of changes. In a critique of the book Jeffreys comments on this vital point as follows:[14]

> "There are many soluble problems involving the steady supply of heat to a conducting solid with an outer boundary at a constant temperature, but they all have a common property, namely, that the heat distribution tends asymptotically to a steady state; there is no possibility of periodicity."

To which Joly replies that, as Jeffreys says, there is no possibility of periodicity according to the mathematical theory of *heat conduction,* but:

> "The periodicity which I have referred to in all my writings on this subject arises from the gravitative instability which affects the ocean floor when an underlying substratum assumes, in consequence of the accumulated latent heat, the fluid state, and becomes of less density than the solid floor. The consequences arising out of this condition allow a very great transfer of latent heat by *convection* from the lower to the upper parts of the magma, so that the upward heat-flux during the fluid phase is very much

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[14] Jeffreys, H., On Prof. Joly's Theory of Earth History, Phil. Mag., series 7, 1, 921-31 (p. 924) and Joly, John, Rejoinder, Op. cit. 932-39 (p. 934), 1926.

greater than the mean, while the upward heat-flux during the solid phase is very much less than the mean."

To this explanation Jeffreys rejoined that convection would not materially modify the results.[15] Because of its bearing on the convection theory subsequently elaborated by Holmes and presently to be considered, we here quote at some length from Jeffreys' statement. Referring to the conditions of convection in a layer of great horizontal extent, in this case a layer of fused basalt, he says:

> "It is of course well known that if a fluid is incompressible, but the density increases with the height on account of variation of temperature or composition, the potential energy can be decreased by interchanging upper and lower layers. This is not, however, a sufficient condition for instability, though it was long believed to be one. Direct interchange of the layers is impossible because they obstruct each other; it can occur only by upward currents in some places combined with downward ones in others, and these are hindered by conduction and viscosity. Consequently instability does not actually arise until the vertical gradient of temperature exceeds a certain finite value. . . . . When the system first becomes unstable, the motion takes the form of a set of polygonal cells, fluid rising in the centers and sinking around the edges. The motion is continuous and steady. . . . . . With increasing gradient of temperature other types of instability arise and other modes of motion become superposed, till we get the complete turbulence known in the ordinary heating of a liquid from below.
>
> Now the horizontal extent of the cells is comparable with the depth. Also the tendency of the currents is to restore the adiabatic gradient of temperature; and the departure from it needed to start them is proportional to the inverse fourth power of the depth, and is negligible when the depth is of the order of a few kilometers. Consequently we must infer that when a fluid is heated at the bottom or internally, the convection currents generated will prevent the gradient of temperature from ever departing far from the adiabatic. Their effect is to carry the heat to the top as fast as supplied; increasing the rate of supply increases the intensity of convective circulation, but not the gradient of temperature. But here we come to the essential point: the heat, on account of the limited size of the cells, always reaches the top within a horizontal distance of the place where it was originally supplied comparable with the depth of the liquid. At the top the liquid is in contact, in the geophysical problem, with the solid upper layer, the bottom

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[15] Jeffreys, H., Prof. Joly and the Earth's Thermal History, Phil. Mag., series 7, 5, 208-214 (p. 212) and Joly, John, Rejoinder, Op. cit., 215-221 (pp. 217-218), 1928.

surface of which must be at the same temperature as the top of the liquid. In the upper layer the heat is transmitted to the outer surface by conduction. The whole thickness of the two layers being of the order of 30 km. a region whose horizontal extent is, say, 100 km. will be thermally practically self-contained. Mutual influence of continental and oceanic conditions will be negligible.

In the terrestrial case the transfer of heat will be partly by way of latent heat; some liquid will solidify when it rises to the top, and the descending currents will contain suspended solid particles, which will gradually melt as they descend. But this does not affect the argument; the only difference is that in the region where the solid is present the gradient is the adiabatic for a mixture of solid and liquid, and not that for a liquid alone. There is no possibility of what Professor Joly calls superheating—that is, rise of temperature far above the melting point. . . . . . Convection simply straightens out part of the graph of temperature against depth, and in no respect facilitates periodicity."

In reply to the last paragraph of the above quotation, which he regards as of prime importance, Joly argues:

"The importance of this passage is in the assumption that descending solid particles will gradually melt away as they descend. Now the accumulation of solid or crystallized magma in the depths is, I believe, as essential to the theory of thermal cycles as it is to Lord Kelvin's contention that a crust forming at the surface of the cooling Earth and breaking up must collect beneath till all is solidified. . . . . . Kelvin was very clear that the gradient of temperature downwards in the cooling Earth must be sufficiently slow as not to annul the effects of pressure in raising the melting point.

In the theory of thermal cycles this condition is equally essential. The crystals rise in melting point as they descend. The thermal gradient must not rise steeply enough to counteract this rise of melting point and cause the remelting of the crystals. This is quite clear, and it directs our attention to extraneous sources of a downward rising temperature gradient. Are there deeper lying sources of heat?"

After considering the assumed diminishing supply of radioactive elements with depth, Joly concludes that neither their past nor their contemporaneous emissions could supply the required energy. Neither could tidal shearing movements. Failing to discover any sufficient reason for assuming a sustained rise of temperature downwards, he concludes:

"But if this high gradient does not exist, then Dr. Jeffrey's steady state must fail. For the congealed basalt must build up from beneath concurrently with the escape of heat from the higher regions of the magma into the overlying solid ocean floor; and the original solid state must in this way be renewed."

Thus it appears that the theory of thermal cycles, involving alternate melting and refrigeration, depends upon the existence of a favorable heat gradient, which in turn must be connected with a rather narrowly defined distribution of radioactive elements in the depth. If we assume, on the one hand, that the heating elements were practically negligible in depth, the earth having once solidified could not be remelted. Or, on the other hand, if the heating elements occur in the depths in sufficient proportion to cause remelting of the substratum under the crust, that proportion must be no greater than is consistent with the maintenance of a temperature gradient that is "sufficiently slow not to annul the effects of pressure in raising the melting point."

Professor Joly's theory thus constitutes a very special case in the group of special theories characterized by the initial assumption of regular distribution of radioactive elements.

Holmes, 1928.[16]

This, the latest of Holmes' contributions to the discussion of terrestrial radioactivity, presents a concept of deep-seated convection currents in a mobile substratum covered by a solid crust.

The discussion is begun by a comprehensive classification of tectonic hypotheses and a very helpful analysis of all previous theories relating to radioactivity and the thermal history of the earth. Each one of them, including his own of 1915, having been found wanting, he first reviews the postulates and then develops the new hypothesis.

It is assumed that:

(1) Radioactivity is not limited to the crust. There being geochemical and physical evidence of a slightly radioactive substratum and accordingly a production of heat over and above that conducted to the surface.

(2) The substratum should still be in a "fluid" or glassy state.

(3) In order to discharge the excess of heat it is necessary to conceive a mechanism, involving circulation of the material

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[16] Holmes, Arthur, Radioactivity and Earth Movements, Trans. Geol. Soc. Glasgow, **18**, Pt. III, 559-606, 1928-29.

of the substratum by convection currents and continental drift operated by such currents.

On the question of convection currents the views of Bull, Ampferer, Schwinner, Kraus, and Born are cited, and it is postulated that the requisite energy is to be found in radioactivity.

(4) With reference to the nature of the crust and substratum the "Upper layer" is regarded as ranging in composition from granite to diorite and as being nearer the average composition of granodiorite than to that of granite. Its thickness is taken as 10 kilometers or more, following Jeffreys.

An "Intermediate layer" exists and consists of amphibolite, which probably passes down into granulite, both facies being subject to local transformation into eclogite under appropirate dynamic conditions.

The thickness of the intermediate layer ranges from 20 to 25 kilometers, or possibly more.

A "Lower layer" may be some form of peridotite, probably in a glassy rather than a crystalline state. It is regarded as "highly rigid" as well as "highly viscous and therefore mechanically indistinguishable from a solid," but it "may nevertheless be 'fluid' in the sense of lacking strength and crystalline structure."

(5) The suboceanic part of the crust is presumably gabbro or amphibolite, and it is likely to be somewhat thicker than the continental layer.

The "lower layer of the oceanic areas cannot be distinguished from that lying beneath the continents, and the substratum appears to be a continuous shell bounded above by the crust and below by the metallic core. The bottom of the shell is 2900 km. below the surface at the contact with the core."

(6) The "average content of the radioactive elements in rocks" and their "heat outputs" are adequately well determined to permit a calculation of the "total generation of heat in average rock-types." The data are tabulated accordingly.

(7) None of the radioactive energy liberated in the earth is "used up in effecting physical, chemical, or atomic changes in the surrounding minerals," a possibility suggested by Dr. J. W. Evans.

(8) There is no inhibition of heat output when the radio elements are deeply buried in the earth.

(9) The earth's radioactivity is strongly concentrated toward the surface. The thermal data, when combined with the seis-

mologic and petrologic evidence, lead to the conclusion that an outer shell, less than 60 km. thick, must generate sufficient heat to make good the loss from the surface. If magma comes from a greater depth (p. 573) there is an excess production of heat, implying the presence of radioactive elements at greater depths. This reasoning is presented in controverting Jeffreys preferred hypothesis of limited radioactivity.

(10) After quoting Jeffreys to the effect that a certain content of radioactive elements would have sufficed to prevent the substratum from ever solidifying, and having fortified this view by estimates based on a radioactive content which is assumed to be only 1/700 of that of plateau basalt, Holmes concludes that:

> "(a) If the crust of the earth makes good the loss of heat by conduction to the surface, and
>
> (b) If the substratum has only 1/700 of the heat generating capacity of plateau basalt; then
>
> (c) The substratum cannot yet have cooled sufficiently to have crystallized, but must still be in the stage of convective circulation, and
>
> (d) To avoid permanent heating up some process such as continental drift is necessary to make possible the discharge of heat."

Holmes thus introduces the problem of convection in a substratum taken to be 2900 km. thick. His statement of the concept cannot well be condensed and is here given in full.

> "In the simple case of an extensive layer of uniformly heated viscous liquid, with rigid conducting surfaces above and below, the conditions leading to convection currents are fairly well understood. There is stability until a certain critical temperature gradient is reached, depending upon the compressibility, conductivity, and viscosity of the fluid. As the critical gradient is exceeded, the uniformly stratified distribution of material becomes unstable, and in the attempt to restore stability a system of complementary currents begins to develop, ascending in some places and descending in others. The disturbances are at first chaotic, but of all the possible systems of movement some tend to persist and to increase steadily with time at the expense of others. This leads gradually to the survival of local centers from which vertical currents ascend. Towards the top the currents spread out in all directions from each center until they interfere with one another, turn downwards, and form sheet-like return currents. Thus irregular polygonal prisms come to be enclosed by the downward currents. Under ideally uniform conditions the polygons would ultimately become hexag-

onal and the diameter of the hexagons would be three or four times the depth of the convective layer (60).

In the earth the critical gradient appears to be about 30° C. per km. So long as this is not exceeded convection must go on, provided that the material has no strength and that the viscosity is not too high."

This passage has been quoted in full because it presents the essential concept of the new theory and its limiting conditions. Convection currents in the substratum constitute the activity to which all other geological effects are attributed. If they may be postulated satisfactorily one may reason further on these lines, but if they fail the particular hypothesis is without motive power.

Holmes postulates that the convection currents have not yet failed. His analysis of the conditions was unfortunately omitted from his paper to shorten it,[17] but we may perhaps quote pertinently from Jeffreys on the subject. The latter, in discussing solidification with radioactivity, says:[18]

> "So long as the earth remained liquid at the surface, the loss of heat was so rapid that radioactivity cannot be supposed to have influenced the course of solidification. But as soon as viscosity became great enough anywhere to stop convection currents radioactivity became a controlling influence."

He then sets up and discusses the mathematical equation for the conduction of heat and concludes:

> "The solid is heated up by radioactivity as if no conduction was disturbing the process. . . . . . The inference is that if convection currents were stopped radioactive heating would at once step in and raise the temperature till they started again; and if the temperature were high enough for them to exist the new heat would be carried up as fast as it was generated. It seems in fact that the effect of heating in this case would be that the interior, instead of cooling until its viscosity was high enough to prevent convection currents entirely, would cool slightly less till the viscosity was high enough to prevent all convection currents except the very feeble ones needed to carry off the new heat."

Continuing this discussion by considering the case in which he assumes that an intermediate layer might stiffen while the interior remained thoroughly liquid, he states:

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[17] Personal communication.

[18] Jeffreys, Harold, The Earth, 2d ed., p. 140-145, 1929.

"Thus the liquid adiabatic gradient would be maintained at great depths until the matter that solidified first had cooled far below its melting point; if indeed this ever took place.

The seriousness of the last proviso is seen when we consider the flow of heat in the ultimate steady state. The rate of increase of temperature with depth near the surface, as we have seen, is about 30° per kilometer. This gradient is enough to carry off the radioactive heat as fast as it is produced, and also some original heat. When the thermal state is steady the rate of flow of heat out of any sphere must be equal to the generation of heat inside it. When radioactive substances were uniformly distributed through the rocky shell, the rate of generation within, say, 100 km. of the surface was a small fraction of the whole, and the gradient down to this depth was nearly as at the surface. Hence the temperature 100 km. down was 3000° C., far above the melting point of any conceivable rock. This result is obtained on the hypothesis that the transfer of heat down to that depth is by conduction, and the temperature found is such that the transfer at it must be by convection. The conclusions contradict the hypothesis, and we must suppose that if the internal generation of heat was no greater than now, but uniformly distributed, the rocks below 50 km. or so could never have solidified. Whatever the mechanism of the original cooling, the heat generated internally was so abundant that it could not be conducted out without temperatures above the melting points of rocks and permanent fluidity would be maintained except in a thin crust. Below this the viscosity might be high, but not high enough to prevent the new heat from being carried up by convection currents and the temperature could never fall to the melting point.

With such an origin as we have supposed, the earth's rocky shell must have been nearly uniform in composition originally. On the other hand the radioactive substances are now strongly concentrated towards the outside. The change is attributed to such a process as Holmes has indicated for the granites of Finland. So long as convection went on, the tendency of the radioactive elements to move upward was effective. As they collected towards the top they left the lower layers empoverished, and the transfer could only stop when the temperature gradient at all depths had become so low as to permit solidification. This implies that the concentration would be almost complete."

A brief statement of the case by Holmes corresponds with the analysis quoted from Jeffreys. Holmes says:

(Page 576) "Granting the physical possibility of convection within the substratum, the effect of radioactivity would be to steepen the gradient over the critical gradient and so to increase the rate of circulation until the new heat could be carried off as fast as it was generated. With the differentiation and crystallization of the crustal materials, the interior would be able to discharge the excess heat only in so far as the crust could be fused or broken through from below. . . . . The mode of circulation of the substratum can be deduced from general principles. It will depend mainly on (a) the varying thickness of the substratum from equator to poles; (b) on the varying thickness and radioactive content of the crustal cover; and (c) on the rotation of the earth; upward moving currents will be deflected westwards and downward currents eastwards; in the northern hemisphere horizontal movements will turn towards the right and in the southern towards the left; such deflections, however, are likely to be very slight . . . ."

Holmes then proceeds to deduce the results of the planetary circulation described under (c) of the above quotation and the modifications which would be superimposed upon it as cyclonic and anticyclonic systems by the effects of greater and less radioactivity in the overlying crust. He characterizes these as "monsoon-like currents due to the distribution of continental blocks and ocean floors." The student may be referred to the original article for this speculative discussion, but we may quote the final summary, with which Holmes concludes his presentation of the convection theory.

(Page 600) "It is not to be supposed that the first presentation of a far-reaching hypothesis and its manifold applications can be wholly free from errors. The workings of the inner earth reveal themselves only indirectly, and their actual nature in space and time is certain to be far more complex than can be visualized. Nevertheless, the preliminary survey that has here been given seems to show that the convection-current hypothesis goes far to account for

(a) The leading features of continental drift since the close of the Paleozoic;
(b) Mountain building and island festoons;
(c) Oceanic deeps;
(d) The initiation and development of geosynclines of various types under both compression and tension;
(e) The growth and disappearance of borderlands;
(f) The varied characteristics of median areas;
(g) Rift valleys;
(h) The distribution of earthquakes;
(i) Igneous activity and the distribution of volcanoes;
(j) Marine transgressions and recessions; and
(k) Possibly the maintenance of the earth's magnetism.

So far the treatment has been almost entirely qualitative and therefore it inevitably stands in need of criticism and quantitative revision., The hydrodynamics of the substratum and its behavior as a heat engine need to be attacked on sound physical lines. The capacity of substratum currents to promote magmatic corrosion, transport and crystallization, and to produce migrating sub-crustal wave forms, calls for detailed treatment. The full bearings of the hypothesis upon petrogenesis have yet to be investigated. Meanwhile its general geological success seems to justify its tentative adoption as a working hypothesis of unusual promise."

In the discussion of the several topics listed from (a) to (k) Holmes develops mechanisms that depend upon irregularities in the distribution of radioactive elements and to this extent he departs in the deployment of his theory from the fundamental, mathematical assumption of an "average" distribution. On this ground he objects to being grouped definitely with the uniform, homogeneous layer advocates. He writes:[19]

"I have discussed irregularities due to (1) variations in rocks and different regions; (2) variations in thicknesses of the crust and substratum; (3) variations due to the formation of geosynclines and mountain roots and to deposition of sediments and denudation; and (4) variations in the substratum due to sinking eclogite and rising basalt."

While this is true, it is to be noted that these irregularities are all superficial. Their effect cannot well be credited with deep penetration. They are also secondary. They spring from the primary assumption of uniform distribution, but they do not modify it. Very different deductions would be in order if it were modified to any appreciable degree. It seems, therefore, entirely in keeping with the essential characteristic of the convection hypothesis as here presented by Holmes to class it with the group that assumes some kind of regular distribution.

We may now proceed to the consideration of the other group of hypotheses, comprising those that postulate notable irregularity of the radioactive elements in the globe as an original condition.

GROUP II.

Hypotheses that postulate an irregular distribution of radioactive elements in the earth.

(a) Chamberlin, 1911, discussed radioactive energy as a coöperating agency, tending to produce heat in addition to that developed by self-compression of the globe and by other molecular changes in the solid, heterogeneous, planetesimal earth.

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[19] Personal communication.

(b) Barrell, 1916, described radioactivity as a cause of the formation of reservoirs of magma in the asthenosphere.

(c) L. H. Adams, 1930, in discussing the character of deep-seated materials with reference to the conditions affecting volcanic activity calls attention to the production of molten magma by local heating in regions where the radioactive content is slightly above the average for the earth's crust.

(d) Willis, 1931, has endeavored to apply to the several current theories of radio-thermal processes the method of multiple hypotheses, as practiced by Chamberlin. That method consists in devising for each and every conceivable hypothesis a critical test, which the hypothesis must meet or fail. The method differs radically from a current practice of setting up a theory, such as that of drifting continents, and then searching for phenomena which it will explain. In applying the method of multiple hypotheses to any hypothesis the first question relates to the validity of the fundamental assumptions. Among radioactive thermal theories there is a group that is characterized by assumptions of some regular arrangement of radioactive elements in the globe. The discussions are mathematical and some assumption of uniform, average distribution is therefore unavoidable. It does not follow that it is natural. On the contrary, it appears from the heterogeneous constitution of the sun, from the kinetic activity of its gases, and from the evidence of heterogeneity in the earth, that any assumption of uniformity in the structure or composition of the globe is wholly artificial and unnatural. Hypotheses that postulate uniformity consequently fail to meet the test of consistency with the facts and must be discarded.

An assumption of irregular distribution is the only alternative and it leads to agreement with Chamberlin, Barrell, and Adams as to the mode of operation of radioactivity in the earth and the resulting effects.

That conclusion is independent of any preference for the theory of a once molten globe or an originally solid, planetesimal earth, since it appears equally impossible that uniformity should result in the one case as in the other. The analysis is presented more fully on a subsequent page.

The irregular distribution of radioactive elements in the earth follows logically from the processes of assembly of the globe and the expectable effects are consistent with its eruptive history. Hypotheses of thermal conditions framed in accordance with the assumption of irregularity meet such tests as have as yet been applied to them and may therefore reasonably be entertained while subjected to any further tests that can be devised.

Chamberlin, 1911.[20]

The author of the Planetesimal hypothesis welcomed the discovery of radioactivity as a source of some part of the earth's internal heat. Before that discovery the presumably high temperature of the interior of the globe had, under that hypothesis, been attributed in part to the self compression of the growing sphere and in minor part to the rearrangement and recombination of molecules within the mass. Contrasting the older theory of a molten globe with the later one of planetesimal growth, specifically with regard to the generation and dissipation of heat, Chamberlin says (op. cit., p. 674):

> "Of the two rival views thus already in the field, the one postulated a plethora of heat at the outset and a gradual loss in all later time, the other postulated at the outset a more limited supply of heat which was increased as compression progressed. The adequacy of such compression to give a sufficiency of heat was a subject of debate from the inception of the view. To the interest that naturally attaches to the discovery of a wholly unexpected agency, . . . there was thus added piquancy in view of its inevitable bearings on the thermal problem of the earth's interior and on hypotheses of the earth's origin."

After considering the evidence of the persistence of radioactive disintegration under all terrestrial conditions of pressure and temperature and discussing the chemical sensibility of radioactive substances with reference to their distribution in sediments and waters, he returns to the subject of their occurrence in igneous rocks (op. cit. p. 677):

> "The special distribution of the radioactive substances among the different kinds of igneous rocks is no doubt full of meaning. . . . The earlier determinations . . . seem to show that the acidic class hold more radioactive matter, on the average, than the basic class, but" later "determinations seem to . . . make the preponderance

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[20] Chamberlin, T. C., The Bearings of Radioactivity on Geology, Jour. of Geol., **19**, 673-695, 1911.

of the one class over the other doubtful. The point of special interest here lies in the inference that, if the liquefaction and eruption of the igneous rocks is dependent on the heat derived from radioactivity, the distribution of radioactive substances in the erupted rocks should be inversely proportional to their temperatures of mutual solution or fusion. But it must be observed that even if such a casual distribution prevailed in the rock matter when it first took the liquid form, this distribution might not persist indefinitely, for selective segregation has apparently taken place during the later processes. . . . The pegmatitic material, in segregating from a granite magma" for instance, "seems to have gathered into itself an unusual proportion of the radioactive substance of the parent mass."

This tendency to concentration in certain segregations has an important bearing on the question of the distribution of radioactive elements in the original magma and its derivatives at great depths, under the hypothesis of an originally completely molten globe, since it is a tendency which opposes uniform distribution. But this is a digression from Chamberlin's discussion.

He comments on the opinion of Strutt that the heat gradient of the earth would be too high if radioactive substances were not concentrated in an outer shell and quotes Joly's determination of the depth of the richer part of the crust as lying between 9 and 15 km. Chamberlin then puts the question which is really fundamental to the later theories of Holmes, Joly, and Jeffreys, namely:

> "If the supplies of heat are generated currently by radioactivity in such abundance that it is necessary to put these severe limits on the distribution of radioactive substances, must we abandon entirely all further consideration of supposed supplies handed down from a white hot earth or from any other form of the primitive earth?"

Realizing the very grave difficulties inherent in that question, he not without humor disclaims all responsibility for finding a solution of the problem, since he had for other considerations already abandoned the molten view.

Chamberlin then continues:

> "Is there among the internal processes previously postulated any that provides a way in which such concentration" of the radioactive elements "at the surface might naturally have taken place, or must we find a new geologic process to fit the new thermal difficulty?"

In approaching the answer to this question he reminds his readers of the fact that the calculations of the heat gradient for the interior of the earth, which were made by Lunn in accordance with the concepts of the Planetesimal hypothesis, gave rather a low rate of rise for the outer 200 miles of the spheroid and he comments:

> "This low development of heat in the outer part of the earth seemed at first thought to present a difficulty of a rather serious nature, but it was believed to be met by the effects of liquefaction and extrusion and these were made the chief basis of an additional approximation to the actual temperature curve.[21] It was held that the rising heat of the interior would reach the temperatures of fusion or of mutual solution of some ingredients in the mixed material much earlier than that of other ingredients, and that the ascent of the portion that became molten carrying its latent as well as sensible heat into the cooler zone would necessarily raise the temperature of that zone. . . . . This extrusive process was supposed to have continued to the present day and to have resulted in a permanent adjustable working curve of accommodation between thermal, fluidal, and mechanical conditions."

Chamberlin discusses at considerable length the conditions, stresses, and evidences of the extrusive process thus postulated and emphasizes the *"fundamental dynamic proposition that energy in mobile and expansive embodiments seeks the surface, while its fixed embodiments are forced more firmly together toward the center."*

Returning to the consideration of the distribution of radioactive elements with special reference to their concentration in the outer shell, he continues:

> "Now if this picture in its working details and in its rather sharp antithesis to the older view is clearly in mind, that part which the radioactive substances may be supposed to play in coöperation with this mechanism without changing the general conception is little less than self evident. The radioactive particles are sources of self-generated heat. Under the planetesimal view the radioactive substances were promiscuously scattered through the mass as it was gathered in heterogeneously from the nebula by the crossing of the planetesimal orbits. . . . The self-heating effects of these disseminated particles were necessarily expended first upon themselves and next upon adjacent matter, and, other things being equal, this homemade heat should give those parts precedence in passing into the mobile state. Normally the mixed

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[21] Chamberlin and Salisbury, Geology, Vol. I, pp. 565-567, 1909.

units that inclosed a radioactive particle should have been as susceptible of partially passing into the liquid state as similar units that were free from radioactive matter. The special source of heat should have turned the balance in favor of the unit immediately surrounding the radioactive particle. Thus the radioactive matter normally became involved in the mobile matter and passed with it to or toward the surface."

Chamberlin thus reasoned that the radioactive elements should have become concentrated in the outer shell of the solid globe as a necessary consequence of their dynamic nature. He finds no difficulty in fitting their activity into the processes of extrusion which involve also the heat due to compression. He concludes the essential part of the discussion by pointing out the relation to the Planetesimal hypothesis, saying (op. cit. p. 692):

"While this outline falls far short of an adequate discussion of the relations of radioactivity to the planetesimal hypothesis, it will perhaps suffice to point out the line of coöperation of the new thermal energy with the new genetic hypothesis. The two seem to coöperate happily. Jointly they seem to furnish a promising basis for a revised thermal geology in harmony with accumulating geologic data in various lines and with the growing evidence of the elastic rigidity of the earth-body as a whole."

Barrell, 1916.[22]

Barrell in reasoning regarding the origin of the earth adopted the fundamental concepts of the Planetesimal hypothesis but found grounds for differing with the author of that theory in regard to the thermal history of the globe. He thought there were cogent arguments for recognizing a once molten state of the whole globe or of some large part of it and he conceived accordingly that the planetesimals or planetoids should have been of such magnitude when they came together as to have caused melting. The more or less completely molten earth solidified, however, and acquired a density stratification by fractional crystallization, but igneous activity continued after the primordial globe had cooled (op. cit., p. 39):

"The cause of the continued generation of new bodies of molten rock in the subcrustal shell, adequate to account for the observed results of later geologic time" (continents and ocean basins) "is thought to lie in the slow accumulation of heat from radioactivity in these depths below the crust. . . . . (p. 42). The small content of radioactive elements in the basaltic shell beneath the granitic crust of the continents would supply that slow increment of heat which is necessary to generate new molten rocks. The granitic shell above, though somewhat richer in radioactive elements, is sufficiently near the surface to lose heat by conduction. The excess heat generated in the asthenosphere is, on the contrary, so deeply buried that it cannot escape in that manner but must slowly transform some of the rock into liquid form. Reservoirs gather until their mass, combined with their decreased density in the fluid form, enables them to work their way through the crust above and demonstrate their existence in igneous activity at the surface of the earth."

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[22] Barrell, Joseph, The Origin of the Earth, 1916, published in Evolution of the Earth and its Inhabitants, R. S. Lull, 1919.

From this fragmentary remnant of his reasoning on radioactivity, which is all that Barrell left us in printed form, we may conclude that he looked upon that source of heat as being somewhat irregularly distributed in the subcrustal shell and capable of producing "reservoirs" of magma. The resulting eruptive activity he conceived to have been similar to that recognized by Chamberlin and to have had similar effects.

L. H. Adams, 1930.[28]

In a brief summary of the views to which his extensive studies in the Geophysical Laboratory at Washington on the characteristics of rocks at temperatures and under pressures up to the limits of experimental investigation have led him, Adams describes "a set of properties for deep-seated materials which are mutually consistent and which agree with the idea of an earth that was once entirely liquid."

Starting thus from postulates somewhat similar to those adopted by the English geophysicists, he reaches conclusions differing from theirs in regard to the distribution of radioactive elements and the consequent effects. Regarding temperature he says:

"The temperature at any depth just after solidification was the freezing point of the rock at that depth and, since only in the outer few hundred kilometers has there been any appreciable cooling, throughout the greater part of the earth it is still at that temperature. If sufficient were known about the change of melting point with pressure . . . . it would be possible to specify exactly the temperature at great depths within the earth. At present, however, all that can be done is to calculate approximately the temperature at moderate depths. . . . . The present temperature at any" (moderate) "depth has been attained through gradual cooling from the freezing point, the cooling being retarded by the small but important amount of radioactive substances within the rock, as suggested by Holmes."

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[28] Adams, Leason H., The General Character of Deep-seated Materials in Relation to Volcanic Activity, Geophysical Union, Reports, 309-314, 1930.

Having described the composition of the earth as consisting of successively deeper layers of granite, diabase or gabbro, and periodotite or eclogite, he continues:

"The amount of radioactive elements in the rocks of the crust is a factor of fundamental importance in geophysics. . . . The amount of heat while exceedingly minute is very significant. With the earth as old as it is (certainly 1,000,000,000 years or more) it turns out that the present temperatures at any depth are almost entirely determined by the radioactive content of surface rocks.

The notable concentration of radioactive substances in granitic rocks has sometimes been considered to be an abnormal and unexpected phenomenon. Uranium, for example, being a heavy element, was expected to settle to the bottom rather than to concentrate at the top. It should be remembered, however, that in a liquid mixture there can be no significant settling out except by a separation into two or more phases. In the crystallization of olivine from a magma there is no reason for believing that uranium would go into solid solution, and thus there is every opportunity for the continuous segregation of this element in the remaining liquid layer. Altogether, the concentration of radioactive minerals in the rocks of the crust and especially in granitic rocks is no more remarkable than the well-known association of the rarer elements with pegmatites."

He next considers three possible sources of liquid lava still occurring within the earth in spite of its great age, namely (1) reservoirs trapped during the last stages of solidification, (2) melting in consequence of a relief of pressure, and (3) local heating due to irregularities in the distribution of radioactive material. He attributes but little importance to the first two conditions. Regarding the effect of bodies richer in radioactive minerals than their surroundings he states:

"Remembering that according to our present views the temperatures at various depths within the earth are almost entirely determined by the average amount of radioactive material in the crustal rocks, we see that a variation in the radioactive content at any place will make the temperature either greater or less than the average temperature for that depth. Even though the total amount of radioactive elements in the rocks is very minute, a small increase in the relative amount at any given locality may raise the temperature above the melting point and thus maintain in that region a supply of liquid almost indefinitely. . . . . Unless there is a very uniform distribution of the radioactive elements throughout the rocks of the earth's crust it seems inevitable that there should be regions in which the temperature is much higher than normal and that we have here an important mechanism for volcanic activity."

It is to be noted that Adams' discussion related to conditions affecting vulcanism and therefore treats of relatively superficial occurrences of magma; but the argument for irregular heating would apply even more cogently to local concentrations of radioactive substances at greater depths.

Willis, 1931.

The method of investigation by multiple hypotheses requires that each and every hypothesis shall be tested, rather than that it should be proved. Marshalling of corroborative evidence is rarely difficult. Testing is difficult and becomes more so the more remote and unfamiliar the conditions of the postulates to be tested. It is therefore with a full appreciation of the difficulties of the problems that I have undertaken to examine the current theories of radioactivity and the earth's thermal history.

As has been indicated in the preceding briefs of theories, they can be arranged in two groups, which are distinguished by assumptions regarding the original manner of distribution of the radioactive elements, whether with such regularity as to produce generally uniform heating or with such irregularity as to create foci of relatively intensely high temperature. Therein lies the crux of the problem.

I did not at first recognize this fact, but was inclined to lay emphasis upon the inadequacy of sampling and the consequent uncertainty regarding the amount of radioactive energy available. Do the available analyses constitute a sufficient basis for the arithmetical results calculated from them? I think the answer is No, they do not; but even if that contention be sustained it can lead to a deferred decision only. And, however completely we might sample the surface rocks, we would always remain ignorant of the richness or poverty of deeper-seated zones. That test is therefore inconclusive at best.

The postulate of uniform distribution of radioactive elements offers a more crucial test of those theories by which it is assumed.

In mathematical discussions of natural phenomena the idea of an *average* is inevitably implied or stated. An average composition, an average temperature, average pressures may be expressed by Greek letters or other symbols, and the latter then become definite representatives of that average or uniform condition. To what degree this artificial uniformity misrepresents the variety of nature we may realize if we consider the scarcity of natural constants. This general observation becomes peculiarly pertinent when we are dealing not with material quantities only, but with dynamic centers.

We find the idea of averages and of uniformity clearly expressed in Jeffreys' discussion of the thermal history of the earth as affected by radioactivity, in Holmes' several papers already cited, and also in Joly's book. The theories must all stand or fall according as it is true or false. The authors logically assume an originally molten earth and the question is thus narrowed to consideration of the degree of uniformity which might reasonably be expected to result from the cooling of such a globe.

In order to do the question justice we should go back to the origin of the materials in the sun, where, because of the low density of that small star, they are supposed to be in a gaseous state at present and no doubt were so at the time of the tidal eruption of the earth-substance. The sun may thus be regarded as a typical gaseous body, which is extremely hot and in which convection currents are actively working in opposition to sorting by gravity. The general assumption is that the resultant effect of these forces is to bring about some degree of stratification in spherical shells arranged according to density, the heavier at the bottom, but that convection constantly disturbs the strata and has prevented the development of homogeneous shells, even after a number of billions of years. Abbot remarks:[24]

> "As evidenced by the sunspots, the prominences, and the corona, there are marked defects of homogeneity in the sun."

It may be argued that the evidence cited is superficial and that a more homogeneous condition exists in deeper layers, but

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[24] Abbot, C. G., The Sun, p. 247, 1911.

Jeffreys, whose analysis of the tidal disruption we may most appropriately follow in this instance,[25] reasons that in the supposed encounter it would be the "envelope" which would be stretched to yield the filament. Since the envelope is heterogeneous we may fairly conclude that the filament itself would from the beginning possess marked defects of homogeneity.

Still following Jeffreys we note that the gaseous filament would pass through a liquid stage, during which it would consist of a liquid core, formed by infalling drops, and a gaseous envelope. This is an effective mechanism for producing density stratification since, other things being equal, the substances having the higher boiling points would be the first to liquefy and fall into the center. Others would follow in the order of liquefaction. But we must not forget that the perfection of the process and its result depend upon the uniformity of temperature from which the cooling begins. If clouds of material having higher boiling points chanced to be hotter while clouds of matter having lower boiling points were enough cooler, the latter might liquefy and fall into a deeper layer than that reached by the former. Now the sun exhibits differences of temperature amounting to two or three thousand degrees C. on its surface, and we have Jeffreys as authority for the view that it has not changed materially since the birth of the earth. It seems probable then that not only the *substance* of the filament, but also its *heat* lacked homogeneity and it is difficult to see how the liquid earth itself could have escaped a notable degree of heterogeneity.

We have next to consider the effects of convection currents in the solidifying globe, and in this problem also Jeffreys is our guide.

In his chapter on the age of the earth (op. cit. p. 79) he says:

> "The liquefaction would be complete when all the latent heat of evaporation had been radiated away, and cooling to the melting point would then proceed. The latent heat of fusion would then have to be lost before solidification was complete. The total loss of heat from the commencement of condensation to the completion of solidification would hardly exceed 2,000 calories per gram. Taking the melting point at 1500° we find that the rate of loss of heat per gram at that temperature would be 1/5 calorie per year. Thus the time between the onset of solidification and its advancement to such a stage that internal convection was stopped could not exceed 10,000 years."

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[25] Jeffreys, Harold, The Earth, pp. 16 et seq., 1929.

It is desirable to note specifically the very brief period of solidification here indicated. Assuming that at the beginning a convection current started upward from a depth of 3000 km. (the actual depth to the surface of the core) it would have to rise at the rate of 1 km. in 3 and 1/3 years to reach the outer surface. Considering that it must overcome friction and rather high viscosity such a column could not be expected to rise and sink at a speed sufficient to make the round trip many times in the allotted epoch. This constitutes a slow stirring process, not appropriate to promote sorting by gravity, yet it has been described as one which produced homogeneous shells.

The convection process has been clearly presented by Holmes[26] as already quoted (p. 209). In attempting to apply the ideal convection sketched by him to the liquid earth we may recall that the hypothetical globe with which we are dealing in this discussion had acquired only a gross stratification according to density, but should retain a notable degree of heterogeneity within that irregular layering. Convection starts in lower, relatively dense materials, which become lighter as they become hotter. They rise into layers of relatively lighter, unless cooler substances. After continuing for a few thousand years the movements are checked by the increasing viscosity. The lodgements finally imposed upon the various ascending and descending masses must necessarily result in the juxtaposition of bodies that differ in composition and in density at the same temperature. Lateral heterogeneity would result, rather than lateral homogeneity, such as is postulated by the assumption of uniform spherical shells.

With reference to radioactive substances, which occupy the center of our immediate stage, we may carry this analysis a little further. Being very heavy minerals they should be found chiefly in the deeper layers after gravitative settling in the process of liquefaction, but possessing the power of self-heating they should develop rising currents at an early stage of convection. Furthermore, they should maintain the high temperature of the magmas in which they were abundant and these should not be carried down again, except as minor bodies included in more massive currents. The resulting concentration in the outer shells has been deduced by Chamberlin, Holmes, and Jeffreys. But the more persistently fluid character of the radioactive magmas would also serve to cause them to coalesce in the ascending and descending streams and thus to form specially characterized bodies which would differ from their surroundings at whatever level they became trapped in the solidifying globe. These considerations lend no encouragement to the idea of uniform distribution of radioactive substances.

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[26] Holmes, Arthur, Radioactivity and Earth Movements, Trans. Geol. Soc. of Glasgow, **18**, 575, 1928-29.

We may still push this inquiry a little further. The subject thus far discussed has been confined to *material* homogeneity. But our question relates to *dynamic* homogeneity. The one is static and once established would remain unmodified during relatively long periods. The other, being dynamic, must increase in degree of diversity from its surroundings until the heating mass became large enough to move by its relative levity or to be squeezed out. Now this eruptive mass is of a different order of magnitude from that involved in the original convection currents. The latter might in the ideal case have had diameters "three or four times the depth of the convective layer," which is assumed by Holmes to be 2900 km. deep. The ideal case, requiring columns say 10,000 km. in diameter, is presumably not conceivable, though Holmes' diagrams of the planetary circulation seem to imply something of that magnitude. But, however we may limit them, the columns involved in the convection currents would be large enough to enclose as minor threads the magmas due to dispersed radioactive elements. The latter would consequently not be free to concentrate independently or to diffuse uniformly. They would to some extent necessarily come to rest in the solidifying globe in whatever shell, at whatever depth, under whatever latitude and longitude they happened to reach.

Thus we conclude that the distribution of radioactive elements could not have been uniform and it follows that hypotheses built upon the unreal assumption of uniformity must themselves lack reality.

The hypothetical thermal history of the globe, which we took as the basis of the preceding analysis, is that set forth by Jeffreys and is the one most favorable to the development of density stratification. We have seen that it starts with a sun lacking homogeneity, and that disturbing influences must have affected the gravitational assembling of the gaseous filament, the liquefaction of the gaseous sphere, and the solidification of the globe. We conclude that the cooled earth could not have acquired homogeneous material shells and must dynamically have become heterogeneous to an even greater degree.

The conclusion that the earth must be materially and dynamically heterogeneous follows even more cogently from a review of its past if we assume that it assembled as a solid according to the Planetesimal theory, and has had an eruptive history.

The resultant earth does not appear to differ in any essential feature of structure or activity from that which we may infer from a study of its surface and dynamic, eruptive history. Thus the hypotheses of Chamberlin and Barrell stand the test of consistency with logical inferences from the processes of earth genesis and with known facts.[9] They are perhaps, as Holmes points out, not to be compared as hypotheses with the elaborate geothermal theories, they do not account for all the activities of the globe considered as a heat engine, but they do assign to radioactivity an important rôle in keeping with its probable character and efficiency.

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SOME NOTES ON THE MELTING OF GRANITE

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There has been considerable discussion concerning the melting interval of granite,[1] but up to the present time there seems to be no unanimity of opinion as to the actual values of these temperatures. Some of this uncertainty can probably be traced to the fact that there is no one clean-cut answer to the problem. For the term granite is used not for a definite composition but to classify a rather indefinite range of compositions. Variations in one or more of the components of granite, within this composition range may alter appreciably the value of the liquidus temperature.

There are also experimental difficulties with which to contend, and it is perhaps owing to the high viscosity of dry silicate melts with consequent difficulty of attaining equilibrium within the time available for a laboratory measurement that some writers have assumed liquidus temperatures for granite to lie above those of gabbros.

It may also be possible that the high melting temperatures of crystalline silica (quartz, tridymite, and cristobalite), have influenced opinions on melting temperatures, although geologic evidence points to the conclusion that granite represents a late stage in fractionation by crystallization from a cooling magma originally more femic.

There is still another consideration to be introduced in any attempt at evaluating the crystallization temperature interval of a granite magma. For all magmas contain volatile components, of which perhaps only a small part becomes bound up in the crystalline phases (granite), the greater portion of these volatiles playing a complex rôle in what are commonly called post-magmatic processes. Of these volatile constituents water is the most abundant, and in this paper is presented an account of some results obtained by melting Stone Mountain granite in the presence of water.

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[1] Granite, like any other mixture of more than one component except a eutectic composition, does not melt or solidify at a point but over a temperature interval. The temperature at which the last crystals disappear or the first ones appear, T_l, is called the liquidus temperature; the temperature at which the first liquid appears or last liquid disappears, T_s, is called the solidus temperature. In the case of granite the temperature at which the last crystals formed is not a true solidus temperature but represents the point at which the residual liquid became separated from the crystalline phases. T_L-T_S is the melting interval for the mixture.

PART I. EXPERIMENTAL RESULTS.

DESCRIPTION OF MATERIALS USED.

The granite used in these melting determinations came from Stone Mountain near Atlanta, Georgia. It is a normal biotite-bearing muscovite granite of light grey color. The granite glass, used in some experiments and listed in the experimental results as such, was obtained by melting this granite in a platinum-rhodium resistance furnace until the glass obtained was essentially homogeneous. The obsidian listed in the experimental results occurs at Cerro Noagua, New Mexico. The composition of the granite and obsidian are given below in columns 1 and 2 respectively. The analyses were made by Dr. E. S. Shepherd of this Laboratory.

	1.	2.
SiO_2	73.39	76.35
Al_2O_3	14.41	12.34
Fe_2O_3	0.09	0.47
FeO	0.70	0.60
MgO	0.27	0.03
CaO	1.05	0.38
Na_2O	3.96	4.29
K_2O	5.07	4.39
H_2O+	0.39	0.91
H_2O-	0.05	0.00
TiO_2	0.27	0.09
ZrO_2	tr.	tr.
P_2O_5	0.57	0.02
Cl	0.03	0.06
S	0.02	tr.
BaO	0.06	tr.
Sum	100.34	99.85
Density	2.66 at 20°C	2.33 at 25°C*

* The density of the normal obsidian is 2.3297 at 25° C, of the ignited obsidian is 2.3372 at 25° C as determined by a pycnometer method using a water thermostat.

EXPERIMENTAL DETAIL.

The granite, ground extremely fine (less than 200 mesh), and water were inserted in a platinum capsule which was then sealed. Sufficient hydrostatic pressure had to be put on these capsules to compensate for the water vapor pressure inside them. The method of loading and sealing the capsules, and description of the bomb used for obtaining the necessary pressure and temperature are given in an earlier paper.[2] When obsidian or granite glass was used the procedure was identical with that for granite.

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[2] Goranson, Roy W., this Journal, 22, 481, 1931.

The experimental results are presented in Tables A and B, the experiment number being listed at the left for reference. The temperature, pressure, and time of run are given in degrees Centigrade, bars, and hours respectively. Temperature was controlled by a regulator operated on the Wheatstone bridge principle using the furnace winding as one arm of the bridge. The regulator controlled the temperature within ± 5° C. Pressure was read on a Bourdon-type gauge which was calibrated by a dead-weight gauge of the Amagat type. The dial is calibrated in kilograms per sq. cm. and can be read to ± 10 kilograms per cm.^{2}, which is sufficiently accurate for the present purpose.

Runs longer than 10 hours were discontinuous, as it was not safe to leave the bomb unattended.

Results obtained on Stone Mountain granite are given in Table A, those obtained on Stone Mountain granite glass and Cerro Noagua obsidian are given in Table B.

TABLE A.

Experimental Results on Stone Mountain Granite.

T denotes the temperature and P the pressure during the run.

A1-30 $T = 1000^\circ$ *C;* $P = 950$ *bars; 1 hour run.*

Granite + no water: no glass observed. The biotite is darkened.

Granite + 2.7% water: about 40% glass.

Granite + 15% water: about 80% glass. Crystalline grains are all rounded and corroded. Hematite plates have formed.

A1-32 $T = 900^\circ$ *C;* $P = 1500$ *bars; 3 hour run.*

Granite + no water: a few small isotropic patches of index about 1.485. Biotite completely altered.

Granite + 4.8% water (water however leaked out sometime during the run); patches of glass of index about 1.498 enclosing branches and scales of hematite. The residual quartz grains are all rounded.

Granite + 3.8% water: all glass of index about 1.488. The glass is sprinkled abundantly with tiny bubbles.

2A-12 $T = 888^\circ$ *C;* $P = 960$ *bars; 3 hour run.*

Granite + 5.3% water: chiefly glass. A few rounded quartz grains are present. Small hexagonal plates of hematite have developed.

2A-8 $T = 862^\circ$ *C;* $P = 590$ *bars; 4 hour run.*

Granite + 8.8% water: Light grey cylinder of glass interspersed with crystalline grains. Index of glass about 1.488.

2A-12 $T = 821^\circ$ *C;* $P = 960$ *bars; 3 hour run.*

Granite + 5% water: about 30% glass. Quartz grains are all corroded and rounded. Hematite and magnetite were observed.

2A-18c $T = 816^\circ$ *C;* $P = 960$ *bars; 21 hour run.*

Granite + 2% water (lost all the water some time during the run): nearly all glass. Only a few rounded crystalline grains present.

2A-12 *$T = 778^\circ$ C; $P = 960$ bars; 3 hour run.*
Granite + 5% water: The crystalline grains are cemented with glass. Hematite has separated out.

2A-18a *$T = 778^\circ$ C; $P = 960$ bars; 4 hour run.*
Granite + 50% water: about 85% glass. The crystalline grains present are all rounded.

2A-20 *$T = 723^\circ$ C; $P = 960$ bars; 33 hour run.*
Granite + 17% water (lost all water some time during run): about 90% glass. Some recrystallization seems to have taken place in the glass, perhaps after the water had seeped out. The original crystals present are all badly corroded.

2A-20 *$T = 723^\circ$ C; $P = 960$ bars; 55 hour run.*
Granite + 20% water: Some portions of the glass seem to be devoid of any crystalline material. Other portions have a few shreds of crystalline material together with development of hematite flakes. Probably less than 0.1% crystalline material.

2A-22 *$T = 704^\circ$ C; $P = 960$ bars; 47.5 hour run.*
Granite + 9.5% water: 50% or more of glass. The crystalline material present consists of rounded feldspar and quartz together with recrystallized hematite. Tiny bubbles are sprinkled through the glass.

2A-23 *$T = 704^\circ$ C; $P = 960$ bars; 102 hour run.*
Granite + 4.4% water: about 70% or more of glass. All but the larger quartz grains have disappeared. There is some recrystallization of hematite flakes and small needles of rather high index. There are also tiny bubbles sprinkled through the glass.

2A-26 *$T = 704^\circ$ C; $P = 960$ bars; 207.5 hour run.*
Granite + 4.2% water: 75% or more of glass. The crystalline grains are chiefly highly corroded quartz. Recrystallization of hematite flakes and small needles of rather high index. Tiny bubbles are sprinkled throughout the glass.

2A-26 *$T = 704^\circ$ C; $P = 960$ bars; 262.5 hour run.*
Granite + 7% water (lost all water some time after 55 hours): about 70% glass. The crystalline grains are chiefly corroded quartz. There is recrystallization of hematite and some colorless needles which perhaps took place after the water had escaped.

1B-24 *$T = 600^\circ$ C; $P = 385$ bars; 460 hour run.*
Granite + water: a small amount of glass was observed. The biotite is completely altered to magnetite and chlorite; the oligoclase has been attacked and probably partially dissolved by the water. Needles similar to those described in the 460 hour run of Table B occur in void spaces.

TABLE B.

Experimental Results on Cerro Noagua Obsidian and Stone Mountain Granite Glass.

3A-28 *$T = 750^\circ$ C; $P = 980$ bars; 4¾ hour run.*
Stone Mt. granite glass + 6.2% water: Recrystallization of hematite and of a few small, high index rods has taken place.

3A-30 *$T = 900^\circ$ C; $P = 490$ bars; 4 hour run.*
Stone Mt. granite glass + 3.7% water: A few scattered rod-like crystals have formed. They are extremely small and probably make up only a very small fraction of a per cent of the whole amount.

2A-2 *$T = 815^\circ$ C; $P = 570$ bars; 4 hour run.*
Obsidian + no water: sintered to a long rod. Some crystallization has taken place, the glass being liberally spattered with tiny birefracting grains.

2A-18b $T = 751^\circ$ *C*; $P = 960$ *bars; 6 hour run.*
Obsidian + 30% water: a few tiny rods have crystallized out.

1B-24 $T = 600^\circ$ *C*; $P = 385$ *bars; 460 hour run.*
Stone Mt. granite glass + 2.6% water: The powder sintered to a dark grey rod during the run. It appears to be a mass of birefracting grains too small to be clearly resolved and it is impossible to estimate the proportion of glass to crystals. Growing out from the glass are long needles or rods which in places form a radiating fibrous mass. These needles extinguish parallel to the elongation or close to it. Elongation is negative. Index 1.64 ± 0.01. In places V-shaped ends were observed. These crystals probably grew from the water-rich solution which had leached the components of the crystals from the glass.

3A-18 $T = 600^\circ$ *C*; $P = 980$ *bars; 4 hour run.*
Stone Mt. granite glass + 7% water: The glass is speckled with crystalline material. There are at least three kinds of crystals present: hematite, laths of plagioclase (?) and needles or rods of index higher than the laths and of negative elongation. In some places the laths and rods radiate from a central crystalline grain and resemble spherulitic growths. In places crystalline grains are arranged in parallel and concentric bands; these bands have a microfelsitic texture. This banding may be a kind of flow structure caused by kneading of the capsule due to pressure changes.

DISCUSSION OF RESULTS.

In the presence of water vapor at 960 bars pressure Stone Mountain granite became completely molten in 3 hours at 900° C; in 55 hours it was more than 99% glass at 723° C with only a few corroded remnants of the larger quartz grains remaining. In 207 hours at 704° C there remained only 20 per cent or less of crystalline material; since the only original material left which could be identified was quartz, this estimate of crystals is probably high. After 4 hours at 600° C Stone Mountain granite glass with 6% or more of water in solution contained numerous tiny crystals. Two distinct species, besides hematite, were observed but could not be identified. One type consisted of plates with the same sign and general appearance as feldspar. The other type was of rods or needles of higher index than the laths and had a negative elongation. In a 460-hour run at 600° C and 385 bars pressure on Stone Mountain granite glass and water, the glass appeared to be essentially crystalline. In this preparation hexagonal outlines were observed which may be quartz, but in none of the other glasses was any material observed which might have been quartz. In order to determine whether quartz would crystallize readily a 3-hour run was made on silica glass plus water at 900° C and 1000 bars. On examination the material was found to have crystallized completely to quartz. Hence, if conditions are suitable, quartz should undoubtedly crystallize from the granite melt.

A 460-hour run was made on granite plus water at 600° C and 385 bars pressure. After the run a small amount of glass, perhaps less than 1%, was observed cementing some of the grains. The biotite had been completely altered to magnetite and chlorite, and the oligoclase grains appeared to be somewhat leached by the water.

The presence of needle-like rods in the glass even up to 900° was rather puzzling. They have indices of about 1.64 ± .01 and negative elongation. Some of these rods had V-shaped ends and in places branched out in a radiating fibrous pattern. One of the runs was of sufficient duration (460 hours), to allow them to grow large enough to permit determination of the foregoing optical data. In this preparation the needles grew out from the glass into the void spaces. (This run differed from the other runs in that a special bomb was built such that the water generated all the pressure and hence allowed voids to remain intact in and around the glass.) The inference is that these needles must have crystallized from the water-rich solution which leached the constituents of this mineral from the glass. There are two non-crystalline phases present in the system; one consisting of water plus material leached from the granite or granite glass, the other consisting of granite glass plus water. The presence of considerable material soluble in the water-rich phase is apparent on evaporating off the excess water after a run, as there was always a white residue left. Whether the rods present in the other glasses had a similar origin is not known, because they were completely enclosed in the glass. They could, however, have grown from the surface of the glass grains and become enclosed on coalescence and flow of the glass.

CONCLUSIONS.

It is concluded that at 700 ± 50° C and under a water vapor pressure of 1000 bars Stone Mountain granite will become, except for hematite, completely liquid. The melt will have 6.5% of water in solution.[3]

Considerable crystalline material formed in granite glass subjected to a temperature of 600° and a water vapor pressure of about 385 bars for 460 hours. A small amount of glass, probably less than 1%, was present in granite subjected to the same procedure. If equilibrium were attained in this time then at about 575 ± 25° and a pressure of 385 bars 99% or more of the silicate portion of the system granite-water will be crystalline.

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[3] Goranson, Roy W., op. cit.

In these experiments the iron present seemed to be almost entirely oxidized by the water vapor and, as it is very insoluble in the granite-water melt, much of it crystallized out as hematite at temperatures below 1200°. At 1200° the glass contained no hematite and was of a light straw color.

PART II. GENERAL DISCUSSION.

There are still insufficient data to give a coherent picture, and, to obtain it, hypotheses which are not fully substantiated must be introduced. Therefore the following discussion will be subject to change as more data become available.

Here the hypothesis to be introduced is an expression of the relation between concentration of water and liquidus temperature of granite.

The initial slope of the melting temperature lowering is given by the equation

$$\left(\frac{\partial \theta}{\partial m_1}\right)_P = \frac{1.9864\theta^2}{18\Delta x_1 \, m^2_1}$$

where θ denotes the absolute thermodynamic temperature, m_1, the mass fraction of granite, and Δx_1, the heat of solution of the last crystalline phase of granite to go into solution in gram calories per gram. This equation, if we assume the heat of fusion to be 100 calories per gram, gives us an initial lowering of 10.5° per 1% of water. It is not applicable, however, except for very low water concentrations. The rigorous general equation cannot be used through lack of data.

The results of Morey[4] on the systems, H_2O-K_2SiO_3 and H_2O-$K_2Si_2O_5$, should give a closer approximation at the higher water concentrations. The initial slope for the system, H_2O-K_2SiO_3, is, according to the foregoing equation, about 10° C per 1% of water. Morey's observed temperature lowerings for the system, H_2O-K_2SiO_3, are: 35.8° C for a

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[4] Morey, G. W., Jour. Am. Chem. Soc., 39, 1207, 1917.

2% water solution, 376° C for a 6.3% water solution. The slope of the liquidus for this system thus steepens considerably with increasing water content. Observed temperature lowerings for the system, H_2O-$K_2Si_2O_5$, are: 8° for a 0.6% water solution, 441° for an 8.3% water solution.

From these values we can now calculate a liquidus temperature for the dry granite, i.e. the temperature at which it will be completely molten. The calculated value is $T_L = 1050 \pm 50°$ C.

The calculated liquidus temperatures in degrees Centigrade (and pressures in bars) of Stone Mountain granite are: 1035 (140); 1005 (260); 963 (400); 908 (550); 840 (730); 750 (930); and 600 (1100) for 1, 2, 3, 4, 5, 6 and 7 weight per cent of water respectively.

As will be observed from the above computation, the liquidus does not have a maximum pressure in the crystallization temperature range of a granite magma. Furthermore, the temperature-pressure-water solubility relations are such that an error of 100° in the calculated temperatures will not affect the validity of the foregoing statement.

The end temperature in the crystallization process of a granite will not be a solidus temperature but the temperature at which this normal process becomes interrupted by a separation of the residual solution from the coexisting crystallized phases of granite.

Wright and Larsen[5] have evolved a set of criteria to determine whether quartz crystallized as the high or low temperature modification, and used it in a study of quartz from granites, dikes, pegmatites, and veins. These criteria have also been used by others for this purpose. The data indicate that quartz in granite, granite porphyry, and aplite dikes crystallized as the high temperature form, and that pegmatite quartz straddled the inversion, i.e. in the initial stages quartz crystallized as the high temperature form and in the final stages as the low temperature form. This would place the initial stage of pegmatite formation as about 700°, the final temperature as perhaps 550° C.

Let us assume we have a granite magma containing 1% of water in solution and at a depth of, say, 10 kilometers. It will begin to crystallize at about 1025° C. Crystallization, with corresponding increase in concentration of water in the residual liquid, will proceed with continued cooling. When the temperature reaches 700° C about 85% of the original magma will have crystallized, the residual liquid containing about 6.5% of water in solution.

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[5] Wright, F. E., and Larsen, E. S., this Journal, **27**, 421-47, 1909.

The residual solution, 15% of the original magma, would be available for the formation of aplites, pegmatites, and quartz veins; of this amount ⅔ would crystallize between 700° and 500°. Of the original magma containing 1% water in solution we would have as final products: 85% of granite (1035°-700°), 10% of aplite and pegmatite dikes (700°-550°), and 5% of quartz veins (500° and lower).

If this granite magma with 1% of water in solution lies at a depth of 4 kilometers crystallization will begin, as before, at about 1025° and continue normally until the temperature drops to 950° when about ⅔ of the original magma will have crystallized. At this point the pressure necessary to hold the increased concentration of water in solution will become equal to the hydrostatic head at this depth. But we know that the pressure-solubility curve is considerably steeper than the temperature-solubility curve at this pressure,[6] hence further crystallization will be accompanied by an ebullition of water.

There are then two coexistent fluid phases—one predominating in silicates and the other in water. Water will continue to boil out of the magma as silicates crystallize. In a 460-hour run at 600° and a vapor pressure of 385 bars less than 1% of the granite had melted. If in this time an equilibrium was reached then there would be little opportunity here for the formation of aplite and pegmatite dikes.

If the original granite magma contained 3% of water in solution at 10 kilometers depth crystallization would begin at about 965° and continue quietly until a temperature of about 700° was reached; at this temperature about half of the system would be crystalline, the solution containing about 6.5% water in solution. The pressure necessary to hold this amount of water in solution at 700° will be equivalent to the hydrostatic head at this depth and thus further crystallization would be accompanied by an ebullition of water with formation of two coexistent fluid phases. This would continue until the temperature-pressure curve dropped below the external load pressure.

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[6] Goranson, Roy W., op. cit.

SUMMARY.

In any attempt at evaluating the fusion conditions of granite there is a multiplicity of variables to consider. For a granite may vary in composition within rather hazily defined limits. Furthermore, granite magmas also contain other constituents, such as volatile material, which are only partially bound up in the minerals of granite. Of these volatile constituents water is the most abundant. In this paper is presented an account of some results obtained by melting Stone Mountain granite in the presence of water.

Part I. Experimental Results.

The granite, ground fine, and water were sealed up in platinum capsules and brought to the required temperature and pressure in a bomb. Pressure was obtained from the expansion of carbon dioxide, and temperature by means of a platinum resistance furnace enclosed in the bomb.

Equilibrium was difficult to obtain at temperatures below 800° C; for example, 50 hours was required to fuse Stone Mountain granite at a temperature of 723° C and under a water vapor pressure of 960 bars.

It is concluded that at 700 ± 50° C and under a water vapor pressure of 980 bars Stone Mountain granite will become essentially completely liquid, the resulting magma containing 6.5% water in solution; that at 575 ± 50° C and under a water vapor pressure of 385 bars the granite will be 99% + crystalline.

Part II. General Discussion.

After assuming a certain relation between liquidus temperatures of granite and solubility of water the liquidus of dry Stone Mountain granite is calculated to be 1050 ± 50°. The general course of crystallization of a granite magma containing water in solution is then discussed.

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KANSAS PERMIAN INSECTS. PART 15. THE ORDER PLECTOPTERA.

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(*Continued from page 134.*)

Family PROTEREISMATIDAE Sell.

Protereismephemeridae Sell. (1907, p. 345).

The family name is changed in accordance with the International Rules, viz. by adding the termination *-idae* to the stem of the name of the type genus, the stem of *ereisma* being *ereismat-*.

Fore and hind wings closely similar, the forewings slightly longer and wider than the hind, but the hind broader near the base. In the position of rest, the wings are held in a vertical plane over the abdomen at an angle of from 30 to 60 degrees to the thorax. The distance between the bases of fore and hind wings being less than their widths, the posterior portions of the two forewings are enclosed by the anterior portions of the hind, which lie outside them (well shown in Specimen No. 5427). Costal margin for the most part nearly straight, curving downwards to the rather narrowly rounded apex from about four-fifths from base. Posterior margin lightly curved except towards base and apex, where the curvature is more pronounced, especially towards the base in hind wings.

Cross-vein system irregular but complete or nearly so. In the imagines, the membrane of the wing is evidently transparent, even when pigmented, and the individual cross-veins for the most part stand out very clearly by contrast. In the subimagines, the membrane is dull, suggesting opacity, and the cross-veins are much less clearly defined by contrast with it.

Costal brace well developed in both wings, 1.5 to 3.5 mm. long, variable in form. Space between costal vein and costal margin always well chitinized, in the subimagines sometimes coriaceous and armed with short setae.

Costal margin finely serrated, more markedly so in the region of the costal brace. Series of short, stiff hairs or short bristles are developed on the *undersides* of the principal *concave* veins, especially on Sc, Rs and MP in a number of forms (possibly all subimagines).

Venation complete, both as regards regular alternation of convex and concave veins right from C to 2A, and also as regards the connections of the interpolated veins. Modes of connection of interpolated veins very variable, but the normal type to which the great majority of the wings conform has all the triads in the form of *protriads* with the sole exception of the middle triad of Rs (2 Rs of Table C on p. 130), which is a *metatriad*. Rs normally connected with MA only by a short basal anastomosis, but sometimes the original basal stem of Rs can be seen arising from R_1 and meeting the upwardly arching MA close to its origin. CuA normally connected by a basal Y-vein with both MP above and CuP below it, but sometimes one or other branch may be missing. Upward archings of M and Cu variable. Triad of CuA always strongly developed, sometimes with additional veins, making a total of five or six reaching the posterior margin from that vein.

In his original paper on this order (1907), Sellards proposed no less than ten genera, of which all but two were monotypic; in all but two of these the generic and specific characters were not distinguished. All the genera except only *Doter* Sell. were included in the family Protereismatidae. Again excluding *Doter,* I now propose also to remove the genus *Misthodotes* Sell. (1909, p. 151, *Dromeus* Sell., 1907, p. 351, nec *Dromeus* Reiche) to a separate family, leaving eight Sellardsian genera to be dealt with here. These are as follows: *Protereisma, Protechma, Prodromus, Bantiska, Rekter, Pinctodia, Mecus* and *Esca.*

As the family Protereismatidae in this restricted sense still includes the great majority of the fossil mayfly wings present in the Yale Collection, approximately ninety per cent of them, I first of all set to work on this material with a view to classifying it into the Sellardsian genera. This attempt was a complete failure. After working through these wings several times, and after having made very careful drawings of all of them that were sufficiently well preserved to promise reliable results, I have come to the definite conclusion that there is only a single well-defined genus in the family, viz. *Protereisma* Sell. In arriving at this conclusion, careful analyses were made of Sellards' genera in the hope of discovering, either in the definitions or in the figures, some reliable characters on which they might have been soundly established, but none such were found.

I think it advisable to put on record here the results of the analysis:

(1) Genus *Protereisma* Sell. (1907, p. 347): Sellards' type, which I have not seen, appears to me to have been undoubtedly a subimago. (Nowhere in his paper does Sellards appear to have been aware that mayflies possessed a subimaginal stage.) Subimaginal characters are indicated in the words "wings thin, and but slightly corrugated," "lax appearance of the wings" (this is said to be due partly to the fact that "the middle vein of the sets of three arises from the upper division," but this statement puzzles me completely), "cross-veins weak." Family characters are included in the generic definition as follows: "Wings elongate; inner border rounded; greatest width near middle of wing; radius thickened at base; cross-veins numerous." The straight costal border holds for all the genera defined except *Rekter* Sell., but the more rounded form indicated there may well be of no more than specific value.

Sellards also states that "the middle vein of each set of three arises from the upper division," though in his figure of the type specimen (op. cit., p. 347, Fig. 3) the dotted portions are restored from a second specimen, and these include the second and third triads of Rs. In the Yale Collection, only 5.4 per cent of the wings possess this character for the middle triad of Rs, so it is unfortunate that the restoration was made from an exceptional specimen. It is quite clear, from my previous analysis of triads, that the mode of connection is unstable and cannot be used as a generic character.

The strong costal brace is a character shared by practically all the wings in the family, if by "strong" is meant "well-developed." The actual strength or thickness of the costal vein and its brace depends too much upon the state of preservation of the wing to be regarded as a reliable character.

One sexual character is included by Sellards in his generic definition, viz. "abdomen long." This is a male character; the contrasted female character may be found in Sellards' definition of *Pinctodia*.

Sellards' second figure of the genotype, *Protereisma permianum* Sell. (p. 348, Fig. 4) shows no venational characters except the brace. His figure of *P. minus* Sell. (p. 350, Fig. 9) shows the middle triad of Rs as a protriad, and his "cubitus" (our vein MP) reaching distinctly beyond the middle of the posterior margin of the wing, though in his short diagnosis of this species he says "the cubitus is short, not reaching beyond the middle of the wing." Again, one judges that the type specimen was a subimago ("wing thin and flat, the veins thin," "cross-veins weak").

The third species, *P. latum* Sell. (p. 349), is not figured, but is easily recognized by its large size and by the brownish color of the wings. This also appears to be based on a subimago.

We must now pass on to select from the definitions of the other genera those characters in which they differ from *Protereisma* Sell.:

(2) Genus *Protechma* Sell. (p. 349, Fig. 8): This genus is based on an imaginal wing ("wing membrane corrugated, although not strongly so; cross-veins of medium strength") and is distinguished from *Protereisma* in the definition only by the pointed apex of the wing. Sellards' figure very strongly suggests to me that this is a deformity. In any case, the Yale Collection contains not a single pointed wing, and I should doubt very much whether such actually existed. If an examination of the type specimen indicates that the apex was actually pointed, then I suggest that the character is of no more than specific value.

In his figure of *Protechma* (Fig. 8), Sellards shows certain characters that are not mentioned in his definition, viz. that the middle triad of Rs is a metatriad, while the first and third triads of Rs are incomplete. The condition of the middle triad should surely have been contrasted with that in *Protereisma* Sell., as the middle protriad is emphasized in that genus. *Protechma* has the normal condition. As the Yale Collection contains no wings with incomplete triads, I suggest that Sellards' figure is inaccurate as regards the rest of Rs. The triad of MA is shown as a mesotriad, not quite complete. The Yale Collection has only two instances of mesotriads, and both of these are on MA.

A reference to the extent of the anastomosis between Rs and MA is given in the words "the media joins the radius well in front of the costal brace." Reference to the figure shows that "in front" means "behind," as the base of the wing is its most anterior portion. The amount of anastomosis between Rs and MA is highly variable and cannot even be used as a specific character. A reference to Sellards' figures for *Protereisma* indicates about the same condition for that genus.

A further variable character is used in the words "the middle division of the sector forks well towards the apex." Sellards' Figure 8 shows this division just slightly distad from half way along R_3. Such a position is obviously no nearer the apex than is shown for *Protereisma* in his Figure 9, for *Prodromus* in his Figure 10, or for *Rekter* in his Figure 6. The character is variable for individual wings and cannot be used to define either genera or species.

(3) Genus *Prodromus* Sell. (p. 349, Fig. 10): From the combined description and figure, it appears that the type specimen on which this genus is founded was an imaginal hindwing. The imaginal characters are indicated in the words "wings corrugated, but not strongly so; cross-veins comparatively strong." The hindwing characters are indicated in the breadth of the posterior margin towards the base, and in the correlated character of the width of the cubital triad with its additional veins ("five-branched at the border"). The figure shows all three triads of Rs as metatriads. Only a single wing in the Yale Collection has this chance combination of triadic characters. The "shallow forking" of R_3 is exactly paralleled in Sellards' Figure 6 (*Rekter arcuatus*), Figure 8 (*Protechma acuminatum*) and Figure 9 (*Protereisma minus*); my own analysis indicates that this character is variable for individual wings and cannot even be allowed specific value. There is, in fact, nothing either in the description or figure for this genus that differentiates it in any way from *Protereisma*. The figure shows that the wing was slightly buckled along MP, so that its actual width could not be correctly measured; allowing for this, it will be seen that its width was somewhat more than the 5 mm. stated by Sellards, while its length agrees with that of the hindwing of *Protereisma permianum*, of which I consider it to be probably an imaginal hindwing, or, alternatively, a hindwing of *Bantiska elongata* Sell.

(4) Genus *Bantiska* Sell. (p. 349, Fig. 7). This genus also appears to have been based upon an imaginal wing ("wings corrugated; cross-veins numerous, regularly placed and of medium strength"). The short description of seven lines for both genus and species gives us little to go upon. The triads of the radial sector are stated to be all protriads, but the figure shows the third triad as incomplete. In the Yale Collection, 7.7 per cent of the wings have three protriads on Rs. The triad of MA is a mesotriad ("interpolated vein arises from directly between the two outer branches"); this very rare condition was also shown in the figure of *Protechma acuminatum*, but without comment. The basal posterior portion of the wing is missing up to CuA, but the wing appears to have been a

forewing. There is not a single character in the description or figure which separates the genus from *Protereisma.*

(5) Genus *Rekter* Sell. (p. 349, Figs. 6, 7; corrected to *Recter,* 1909, p. 151). The characters which invite attention in the definition of this genus are the "arched" form of the costal margin, the closeness of the costal vein to the margin, and the bend in MP at the origin of its triad. Unfortunately the figure shows that the wing was buckled; most of Rs is omitted from the figure and the space left is not of sufficient width to be normal; so that it is a fair inference that the distal curvature of the costal margin is at least partly due to this cause. The condition described for the costal vein occurs in a number of wings in the Yale Collection which otherwise have straight or nearly straight costal margins, including one excellently preserved wing of *Protereisma latum* Sell. The bend in MP at the origin of the triad is a character not to be found in a single wing in the Yale Collection; as Sellards' figure shows that MA is almost as much bent at the corresponding point, it is fair to assume that the bends were the result of the buckling acting on the veins at their weakest points. The triads of Rs are all said to be protriads; but as their origins are missing except in the case of the distal triad, this seems to involve guesswork. MA is said to "divide early," i.e. near the base, but the figure shows a position little nearer than in *Prodromus rectus* Sell., i.e. about the middle of the wing. Quite a number of wings in the Yale Collection which otherwise belong to *Protereisma* in all characters have the triad of MA arising in this position, though none have it any nearer the base. The statement that "cubitus branches very tardily" means that the triad of MP arises more distally than usual. The figure shows a position about one-third from base or slightly less; this is nothing exceptional, for an analysis of the Yale Collection wings shows that this triad may arise at any point from one-eighth to almost one-half of the length of the vein. In this respect, the triad of MP is the most variable of all.

The above analysis is made from the description of *Rekter arcuatus* Sell., which is the genotype. The wing appears to have been that of a subimago ("wing membrane not strongly corrugated; cross-veins are uniformly and regularly placed"), and the type of buckling also suggests this.

A second species, *Rekter extensus* Sell. (p. 351, Fig. 7), is based on two fragments of wings. It is only doubtfully referred to this genus; and indeed the amount of curvature to be seen in the costal margin is not great. Probably the actual amount of curvature in the unbuckled wing of *R. arcuatus* was about the same as in this fragment.

There are three wings only in the Yale Collection which show an undoubtedly "arched" or curved costal margin, and all belong without any doubt to the genus *Protereisma*. The shape of these wings may be considered as a good specific character, but nothing more.

(6) Genus *Pinctodia* Sell. (p. 352, Fig. 11): The two specimens on which this genus is based have only the basal portions of the wings left. The sole generic character is the stout build of head, thorax and abdomen. I can see nothing in these characters except what we should expect in the females of the genus *Protereisma*. Also, Sellards' figure shows at the end of the abdomen a trapezoidal plate which strongly suggests the ventral plate of a female mayfly. Unfortunately no female abdomens are preserved in the Yale Collection, so I am not able to study this structure more fully.

(7) Genus *Mecus* Sell. (1909, p. 151, *Scopus* Sell., 1907, p. 352, Fig. 12, nec *Scopus* Megerle): This genus is based on a male type specimen with abdomen almost complete (and closely resembling that of *Protereisma*) and fragments of two wings, one fairly complete. One gathers that the specimen was an imago, as the wings "notwithstanding their thin texture, are strongly corrugated." The generic characters are the narrowness of the wings and the general slender build, which "give to this genus much resemblance to the Zygopterous Odonates." From this remark it is clear that Sellards understood the "Zygopterous Odonates" very imperfectly. The triads of Rs are stated to be protriads; the figure shows the interpolated veins attached very close to the forks, which is a characteristic of narrow wings. The deeply forked MA resembles that of *Rekter arcuatus* Sell., but the straight costal margin and narrower costal and subcostal spaces are very different from the corresponding characters in that species.

There are a number of wings in the Yale Collection which agree in slenderness with those of *Mecus gracilis* (Sell.), but it is very evident that they are generically not distinct from *Protereisma*, though I think that a good species is indicated.

(8) Genus *Esca* Sell. (1909, p. 151, *Therates* Sell., 1907, p. 354; nec *Therates* Latr.): This type of wing is not figured, but is evidently based on a subimago ("wings slender, thin and but feebly corrugated; cross-veins numerous but

weak"). The generic characters are based on the costal brace, which is "strong and reaches 3 to 3½ mm. from base," on the later origin of MA from Rs, and on the close approach of MP to the radius. The last two characters are clearly shown in the figure for *Protereisma minus*. The wing has an estimated length of 15 mm. Unfortunately the only wings of about this size in the Yale Collection, with the exception of the slightly larger wings of *Protereisma minus* Sell., have the costal brace very short and the cross-veins rather wide apart, and show little resemblance to *Protereisma;* moreover, the costal margin is markedly curved. The Yale Collection does, however, contain undoubted specimens of wings of *Protereisma* with the costal brace reaching from 3 to 3½ mm. from base. As the costal brace is so long, it is not surprising that "the media fuses with the radius back of the costal brace, not in front of it as in the other genera described." Nevertheless, I have not been able to discover a single wing in the Yale Collection in which this character occurs, and only five in which the distances are equal. Unfortunately no figure of this genus is given by Sellards, and no characters are offered in the definition whereby the status of the genus might be determined, though such might well be found by an examination of the type, seeing that it is said to be "aberrant" and "probably indicating a subfamily."

The result of the above analysis convinces me that all the above genera except *Esca* Sell. must be merged into the single genus *Protereisma* Sell. *Esca* itself must unfortunately be left out of account in this paper, as I have not seen the type and there is nothing resembling Sellards' description of it in the Yale Collection.

Genus *Protereisma* Sellards.

(Figs. 5, 13-18.)

Protereisma Sellards, 1907, p. 347.
Protechma Sellards, 1907, p. 349.
Prodromus Sellards, 1907, p. 349.
Bantiska Sellards, 1907, p. 349.
Rekter Sellards, 1907, p. 349.
Pinctodia Sellards, 1907, p. 352.
Scopus Sellards (nec *Scopus* Megerle), 1907, p. 352.
Mecus Sellards, 1909, p. 151.

This being the only genus in the family Protereismatidae, the characters of the genus may be taken as those already given for the family on p. 237.

Genotype: *Protereisma permianum* Sellards.

Horizon: Lower Permian of Kansas.

There are eighty-six specimens in the Yale Collection which belong to this genus. To separate these into recognizable species is an extremely difficult task. In classifying recent mayflies, many other characters are made use of for specific determination besides those found in the wings. Of the wing characters, two of the best are given by the shape and venation of the reduced hindwing (which are often surprisingly different in otherwise closely related species) and by the color patterns of the wings, more particularly that of the subimago. In the fossil forms, the hindwings are not reduced, and, further, it is not possible to determine definitely the differences between fore and hind wings of a single species. This could only be done if a number of fairly perfect specimens were available with venations of fore and hind wings preserved. In a previous paper (1926) I had assumed that the forewings were much narrower basally than the hind. There is only one specimen in the Yale Collection which is complete enough to allow of a safe comparison. This specimen (*No. 5427*) belongs almost certainly to the genotype, *Protereisma permianum* Sell., and supplies us with the following measurements:

Forewing: Length 19.7 mm.; greatest breadth 5.4 mm.; ratio of length to breadth 3.62; breadth 3 mm. from base 3.75 mm.

Hindwing: Length 18.7 mm.; greatest breadth 5.2 mm.; ratio of length to breadth 3.57; breadth 3 mm. from base 4.5 mm.

Taking each forewing measurement as 100, this result may be expressed in the following way:

	Length	Greatest breadth	Breadth at 3 mm. from base
Forewing	100	100	100
Hindwing	94.9	96.3	120

It will thus be seen that the most reliable criterion for separating fore and hind wings is their comparative breadth near the base. The extra breadth of the hindwing carries with it, of course, a more extensively developed anal venation. Where the base of the wing is preserved, fore and hind wings can usually be picked out, though care must be taken in distinguishing the hindwings of narrow-winged species from the forewings of broad-winged species. In many specimens, however, this criterion is lacking, and then one is thrown back either upon one's knowledge of the average lengths of fore and hind wings for the species, or on a somewhat risky observation of the *trend* of curvature of the posterior margin, as far as it can be followed towards the base.

One character which may be used, with a certain amount of caution, in separating the species of *Protereisma,* is the actual size of the wing studied. Undoubtedly there must have been a certain amount of variation in the actual lengths and breadths of individual wings in the same species, and some of the measurements would almost certainly overlap in different species. However, there are some striking differences which are certainly of specific value, and these will be made use of in the Key. There, it will suffice to state the limits of length and breadth for the forewing only, bearing in mind that the hindwing is on the average about 5 per cent less in length and very slightly less in breadth than the forewing.

In correlation with actual size, there appears to be a rather striking difference in color-pattern of the wings. One group, consisting of two species which are easily the largest in the genus, has a very definite brown pigmentation developed over the whole or a considerable part of the wing-membrane, whereas the other group, containing all the smaller species, has the wings of the imago either wholly hyaline or with only a very slight brownish tinge on them, while the wings of the subimago are slightly opaque, either with the slightest tinge of brown on them, or entirely without any. This character is also made use of in the Key.

Normally in the genus *Protereisma* the cross-vein system is of the type that can be described as fairly dense. In working through the wings of this genus, there is one group that at once strikes the eye as having a definitely less dense system of cross-veins, coupled, in the imago, with marked hyalinity of the wing-membrane. This character has been made use of, for this one species, in the Key; but the general variability of the cross-vein system in individual wings, and the impossibility of making accurate counts when most of the specimens are incomplete and the cross-veins not always very clear, precludes such a character as this from being used more extensively.

Definite venational characters not subject to considerable variation are not easy to find; partly because of the great variability in so many points, which I have already dealt with in detail, and partly because so few of the wings are complete. If Sellards' drawing of the forewing of *Protereisma minus* is correct (1907, p. 350, Fig. 9) this species was exceptional in having a nearly straight CuP except for its usual basal arching. There is only one specimen in the Yale Collection which appears to me to belong to this species; I propose to include it provisionally in the Key until somebody has an opportunity of studying the type.

Some of Sellards' species must fall as synonyms. I hesitate to add any more new species, but two appear to be required to receive two wings which possess some very marked characters different from anything described by Sellards.

KEY TO THE SPECIES OF PROTEREISMA SELLARDS.

1. Species of medium size, i.e. forewings from 16 to 20 mm. in length, their greatest breadth from 4.5 up to 6 mm. Wings without any very definite brown pigmentation on membrane ....2.
Species of large size, i.e. forewings from 24 up to as much as 30 mm. in length, their greatest breadth from 7.5 up to 9 mm. Membrane of wings with a definite brown pigmentation, either wholly or in part..7.
2. Costal margin straight or nearly so for most of its length, only curving downwards from a point already close to apex ....3.
Costal margin strongly arching downwards from a point about one-third of the wing-length from apex ....*P. arcuatum* (Sell.).
3. Costal vein exceptionally close to costal margin of wing; cross-vein system definitely less abundant and more open than in other species.
P. elongatum (Sell.).
Costal vein normally placed; cross-veins abundant ....4.
4. Costal space not exceptionally narrow at base; Sc and R not fused basally; costal vein more or less arched, the brace very stoutly developed ....5.
Costal space very narrow throughout; Sc and R fused basally; costal vein almost straight, the brace short and not so strongly developed.
P. gracile (Sell.).
5. CuP almost straight except for basal arching; forewing about 16 mm. in length ....*P. minus* Sell.
CuP strongly waved; forewing from 18 to 20 mm. in length ....6.
6. CuP exceptionally arched near base and practically touching M; triad of MP arising very close to level of brace-vein ....*P. sellardsi*, n. sp.
CuP normally arched; triad of MP arising well distad from level of brace-vein ....*P. permianum* Sell.
7. Forewing about 25 mm. in length, greatest breadth about 7.5 mm. Brown pigmentation covering the whole or almost the whole of the wing-membrane ....*P. latum* Sell.
Forewing presumably about 29 mm. long and at least 9 mm. wide (hindwing 27 mm. or more long and 9 mm. wide). Brown pigmentation confined to an irregular area near middle of wing ....*P. insigne*, n. sp.

Protereisma permianum Sellards.

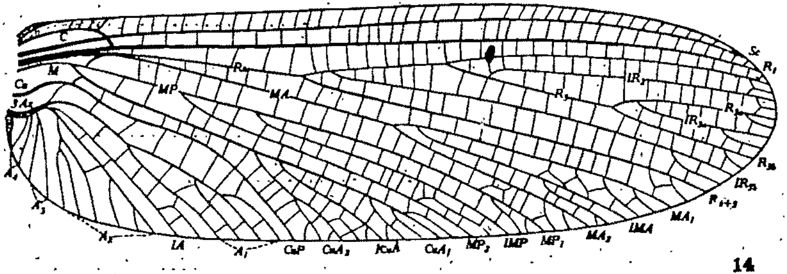
(Figs. 5, 14.)

Protereisma permianum Sellards, 1907, p. 348, Figs. 3, 4 (Subimago).
(?) *Protechma acuminatum* Sellards, 1907, p. 349, Fig. 8 (? Imago).
(?) *Prodromus rectus* Sellards, 1907, p. 349, Fig. 10 (Imago, hindwing).

Length of forewing from 18 to 20 mm.; *greatest breadth* from 5 to 6 mm. *Hindwing* from 17 to 19 mm. in length; *greatest breadth* only slightly less than that of forewing; breadth near base markedly greater than in forewing.

Subimago with wing-membrane slightly opaque and dull, either greyish or very faintly tinged with pale brownish all over; cross-veins not very clearly defined in contrast with membrane. *Imago* with hyaline membrane and with thin but much more clearly defined cross-veins of a brown color.

Costal space near base wider than subcostal, but towards the middle of the wing they tend to become equal in width, and beyond that the subcostal space is the wider. Costal brace stouter in subimago than in imago; also the area around the costal vein more strongly chitinized and the costal margin of the wing more strongly serrated in the subimago. Forewing with triad of Cu_1 well developed, sometimes with extra terminal twiglets. Hindwing with this same triad widely spread out and with definite additional branches usually developed on the outer branches though seldom on the interpolated vein. Cu_2 pursues a markedly sinuous course in both wings. Anal system of veins well developed, the hindwing with a long triad on A_1.



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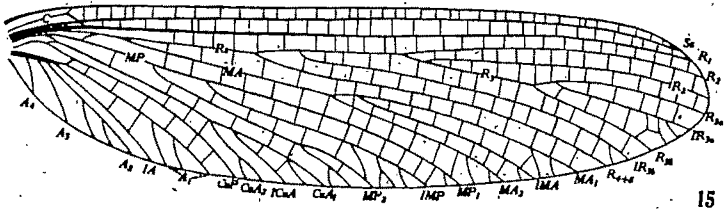

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Fig. 14. *Protereisma permianum* Sellards. Restoration of complete hindwing, based principally on Specimens No. 1103 and 5427.

Fig. 15. *Protereisma gracile* (Sellards). Restoration of complete forewing, based principally on Specimen No. 5438.

Venational notation in both figures as adopted in this paper. (See Table on p. 111) *3Ax*, third axillary.

Costal margin very nearly straight to near apex; apex evenly rounded.

Types: Holotype in Sellards' Collection, not numbered in his description, and consisting of head, thorax, first seven segments of abdomen, and fore and hind wings complete but with parts of the venation indistinct. *Paratype* male in Sellards' Collection, also not numbered, with body almost complete, parts of legs, and bases of both wings. The holotype is apparently a subimago.

The following specimens in the Yale Collection appear to me to belong to this species:

Specimen No. 1103 a-b: Hindwing of an imago, complete except for loss of basal portion of anal region. *Length* 19.6 mm., *greatest breadth* 5.6 mm. Membrane subhyaline with very slight brownish cloudiness over central and apical portions; veins brownish, paler distally; cross-veins thin but very distinct in basal half of wing.

Specimen No. 1114 a-b: Probably the forewing of an imago, with about the basal two-thirds of posterior margin missing. *Length* 19.4 mm.; *greatest breadth* approximately 6.2 mm.

Specimen No. 1119 a-b: Hindwing of a subimago, the reverse impression almost complete but obverse with apical portion missing; in both impressions a long, slender femur and tibia lie across the wing and cut off part of the anal area. *Length* approximately 20 mm.; *greatest breadth* 5.7 mm. Venation faint; cross-veins faint and mostly not clear-cut; membrane slightly opaque and tinged with very faint brownish; separate origins of Rs and MA well preserved.

Specimen No. 1120: Reverse impression of hindwing of a subimago, with anal area and extreme apex missing. Membrane opaque, pale greyish; cross-veins moderately clear in basal half, very faint distally. *Length* approximately 19 mm.; *greatest breadth* 6.6 mm.

Specimen No. 5427: A practically complete specimen of a subimago, obverse only, showing meso- and metathorax, practically the whole abdomen, portions of the tail-filaments and male genitalia, and all four wings complete, folded back over the abdomen in the position of rest, the costal portions of the hindwings evidently enclosing between them the posterior portions of the fore. Measurements of the wings as given on p. 245. *Abdomen* about 17 mm. long by 2.2 mm. wide near base; color dark brown with mostly paler sutures between segments; spiracles visible. Wing-membrane somewhat opaque and tinged with light brown; where the wings overlap, this color is darker. Cross-veins indistinct. Cerci and appendix dorsalis weak and somewhat collapsed, as often in subimagines. This specimen forms the basis for the restoration of *Protereisma permianum* Sell. in Figure 5.

Specimen No. 5428 a-b: Forewing of subimago; obverse practically complete, reverse with portions of apex, anal area and extreme base missing, but showing excellently the separate origins of Rs and MA. Membrane slightly opaque, tinged with greyish brown, a little darker near middle; costal space brownish for 3 mm. or more from base. *Length* 18.5 mm., *greatest breadth* 5.5 mm.

Specimen No. 5429: This specimen contains two separate fragments of wings, both probably belonging to a subimago. The distal two-thirds of what is probably a hindwing is preserved as an obverse, and near it the basal half of the reverse of a forewing, with anal area folded over. Membrane slightly opaque, greyish.

Specimen No. 5430 a-b: Two hindwings superimposed, probably of a subimago; membrane with slight brownish tinge, more marked near base; cross-veins brownish, faint. *Length of fragment* (obverse) 17 mm., representing a total length of about 18.5 mm.; *greatest breadth* 6 mm.

Specimen No. 1105: This specimen contains two wings, both forewings of imagines, on the one piece of rock. One wing is practically complete, a reverse impression, measuring 21.5 mm. long by 6 mm. wide, but with the extreme basal part of the anal region missing. When sent to me, this specimen had evidently been much exposed to weathering, but the basal part of the wing was partly covered up by superimposed rock. In removing this, not only was the base of the wing exposed, with its veins darker than those of the weathered portion, but a portion of a second forewing was also brought to light, showing the anal and part of the cubital areas, somewhat crumpled and scraped by the scalpel.

Specimen No. 5433 a-b: Wing of an imago; *length* 17.0 mm., *greatest breadth* 5.3 mm. Obverse complete except for slight damage to apex and loss of anal area by an oblique tear from base to end of Cu_{1b}; reverse showing only a part of the basal half, with costal brace preserved.

Specimen No. 5436 a-b: This specimen contains the remains of two rather poorly preserved and fragmentary subimaginal wings; the reverse shows about the basal two-thirds of one wing, with apical and posterior margins missing and a clean break right across the wing at the level of origin of the basal triad of Rs, together with a fragment of a second wing; obverse very fragmentary.

Specimen No. 5437 is a poorly preserved imaginal wing, with slight brownish tinge on membrane. *Specimen No. 5445* is the obverse of a complete imaginal forewing, unfortunately with the rock surface badly weathered and the venation abraded. *Specimen No. 5449 a-b* shows the basal portions of two hindwings overlying one another and consequently indistinct. *Specimen No. 5450* is the reverse only of a basal fragment with good brace and striking formation of Rs and MA.

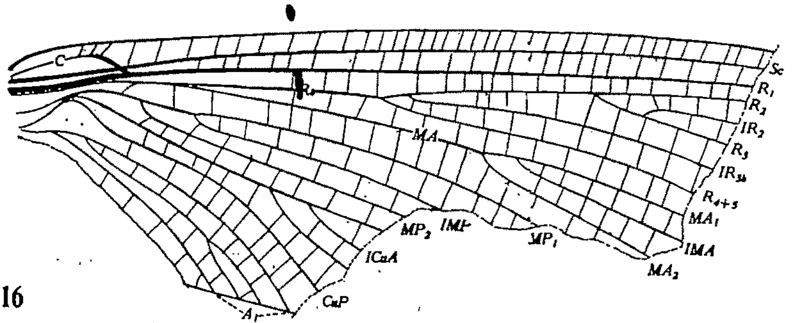

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Fig. 16. *Protereisma sellardsi*, n. sp. Specimen No. 5434, drawn with apex to right.

Protereisma sellardsi, n. sp.

(Fig. 16.)

This species is based on a fragment of the reverse impression of an imaginal wing, probably a hindwing, beautifully preserved. *Length* of fragment about 14 mm., *breadth* about 5.2 mm., indicating a wing of *total length* about 19 or 20 mm. and *greatest breadth* about 6 mm. The specific characters are the extreme basal arching of the cubitus, the very early origin of the triad of MP, which arises at a level only just distad from that of the end of the costal brace vein on R_1, and the very numerous, closely set cross-veins in the costal space. The formation of vein A_1 also appears to be characteristic. The costal vein and brace are very well preserved and the separate origins of Rs and MA quite clearly shown (Fig. 16).

Type: Holotype wing (reverse), *Specimen No. 5434* in Yale University Collection, with base to right.

This species serves in some measure as a connecting link between the genotype, *P. permianum* Sell., and the next succeeding species, *P. gracile* (Sell.).

Protereisma gracile (Sellards).

(Fig. 15.)

Scopus gracilis Sellards, 1907, p. 352, Fig. 12.

Length of forewing 16 to 17 mm., rarely 18 mm., of hindwing, 15 to 16 mm.; *greatest breadth* 4.0 to 4.5 mm., rarely nearly 5.0 mm. The species is distinguished by the narrowness of the wings, by the fact that the costal space is throughout (except at extreme base) narrower than the subcostal, by the basal fusion of Sc and R, and by the numerous and fairly regularly placed cross-veins. The costal margin is very straight, the costal brace weaker than in the two previous species, little curved. The wing of the subimago is distinguished from that of the imago merely by being slightly opaque and with the cross-veins less well defined; there is no trace of any definite tinting.

Sellards' type specimen showed portions of the thorax and one leg, with one hindwing outspread but only partially preserved, a fragment of a second wing, and an almost complete abdomen, the specimen being a male and showing part of the external genitalia and tail filaments. One specimen in the Yale Collection (No. 5435 *a-b*) shows part of the thorax and abdomen, from which we gather that the build was definitely somewhat slenderer than in *P. permianum* Sell.; the second abdominal segment was about as long as broad, but the following ones are all markedly longer than wide. In this same specimen also there is preserved a large part of the hind tibia, which measures at least 8 mm. long by about 0.3 mm. wide, and is clearly carinate along a line running just above the ventral surface.

In Figure 15 I offer a reconstruction of the forewing of this species, based on drawings made of all the better preserved specimens present in the Yale Collection.

Type: Holotype in Sellards' Collection, not numbered in his description, and consisting of parts of two wings, thorax and one leg, and almost the whole abdomen. The specimen would appear to have been an imago.

The following specimens in the Yale Collection appear to me to belong to this species:

Specimen No. 1104 a-b: A complete and fairly well-preserved imaginal hindwing, with anal area torn and some slight abrasions in places. Obverse with apex to right. The close approximation of the main veins at base and the form of arching of CuP are well shown in this specimen.

Specimen No. 5435 a-b: Portion of thorax, basal portions of fore and hind wings, most of abdomen and one hind tibia.

Specimen No. 5438: The reverse impression of the forewing of an imago with basal two-thirds preserved in fair condition, the base to the right; the costal margin and brace are well preserved, but part of the anal area is torn away and there is also a tear in the posterior margin just beyond end of CuP. Besides the basally fused Sc and R, one notices in this narrow-winged species the very close approximation of all the main veins basally, CuA arising from the same stem as MP, and CuP having rather a flattish arch and arising very close below CuA. The third axillary is also placed quite close below the base of Cu, and the anal veins run off from it somewhat more longitudinally than usual in this genus, while the distal branching of A_1 can scarcely be dignified by the name of a triad.

Specimen No. 5440: Portion of an imaginal wing, with extreme base missing and also apical fifth and part of posterior margin. Breadth about 4.5 mm. This was probably a hindwing, but the anal veins are not quite fully spread out.

Specimen No. 5441: Apical half only of an imaginal wing, beautifully preserved, with only a tiny piece missing just above apex. Obverse only. The break in the wing runs slightly basad from the middle triad of Rs, transversely and slightly irregularly across the wing. Apex to the left.

Specimen No. 5442 a-b: A poorly preserved forewing of a subimago, rather distorted at base, and only doubtfully referable to this species. Obverse fairly complete but with apex missing; reverse only a fragment.

Specimen No. 5444 a-b: Basal half of imaginal hindwing; obverse fairly well preserved, with good anal area; reverse poor. In contrast with practically every other specimen of *Protereisma* in the collection, the anal area of this specimen is the best preserved portion.

The following also belong to this species: *Nos. 5446 a-b* (distal half of imaginal wing, well preserved), *5447* (nearly complete obverse of imaginal forewing), *5448 a-b* (good fragment of imaginal wing), *5431* (poorly preserved subimaginal forewing).

Protereisma minus Sellards.

Protereisma minus Sellards, 1907, p. 348, Fig. 9.

Type: Holotype, subimaginal forewing in Sellards' Collection, not numbered in his description.

Sellards gives the measurements of the wing of his type specimen, evidently a forewing, as 16 mm. long by 4⅔ mm. wide, i.e. considerably less than the average for *P. permianum.* He distinguishes it from the latter also by the comparative shortness of the vein which he calls the cubitus, i.e. MP, and which, he states, does not reach beyond the middle of the wing. His Figure 9, however, shows it ending at about four-sevenths of the distance along the posterior margin.

I am not at all sure that this species can be maintained. In Sellards' Figure 9, the costal brace is shown as of the same type as in *P. permianum,* but there is a wide space following it without any cross-veins; also vein CuP, apart from its basal arching, is remarkably straight. I think that actually Sellards missed seeing one or two cross-veins following the brace, and also that CuP could not have been as straight as he figures it.

In the Yale Collection, *Specimen No. 5451* shows the obverse of the basal half of a subimaginal wing 4.5 mm. wide, and evidently not more than 16 mm. long when complete, which appears to agree with Sellards' type in the form of Cu_1, and may be provisionally associated with it under the name *P. minus* Sell. It seems highly probable that a study of more material would show that this small form should be merged with *P. permianum.*

Protereisma elongatum (Sellards).

Bantiska elongata Sellards, 1907, p. 349, Fig. 7.

Type: Holotype, imaginal wing, probably a forewing, in Sellards' Collection, not numbered in his description.

I think this is a good species, which can be distinguished almost at once from all the rest by the less dense cross-vein system combined with the very clear hyaline membrane of the imaginal wing, the straight costal margin and the closeness of the costal vein to the costal margin. Measurements of forewing are: *length* 16 to 20 mm., *greatest breadth* 5 to 6 mm., indicating that the wing is not in any sense particularly elongate. The cross-vein system is also rather open in *P. latum* Sell., a much larger species distinguished by many good characters.

Specimen No. 1102 a-b: Hindwing of an imago, the obverse complete except for slight damage by chisel to anal area, but lying on a very uneven rock surface; the reverse with considerable part of apical area missing and also a small part of anal area. *Length* 17.5 mm.; *greatest breadth* 5.5 mm. Venation beautifully marked, the cross-veins fine but distinct right to apex; separate origins of Rs and MA and their mode of anastomosis well shown.

Specimen No. 1113 a-b probably represents a subimaginal wing, with apical portion missing.

Specimen No. 5432: Reverse of a nearly complete hindwing; *length* 19 mm., *breadth* about 5.7 mm. Third axillary preserved in excellent condition, darkly pigmented; origin of triad of MA with veins darkened.

Specimen No. 5439: Reverse of an imaginal wing in excellent condition. Anal area and portion of posterior margin missing, and a large piece removed from wing at about one-third from base, causing slight sagging of the remainder; Sc remains complete, but R_1 is broken; apex missing.

Specimen No. 5453 a-b: Forewing of imago, the reverse impression being the more complete. *Specimen No. 5454* is the obverse of an imaginal wing distorted by the uneven rock surface; costal vein very close to costal margin.

Protereisma arcuatum (Sellards).

(Fig. 17.)

Rekter arcuatus Sellards, 1907, p. 349, Fig. 6.

Type: Holotype wing, probably imaginal, in Sellards' Collection, not numbered in his description.

This species I consider very close to the previous one, and only to be distinguished from it with any certainty by the marked curvature of the costal margin, which starts to arch downwards towards the apex at a point somewhere about one-third of the wing-length from the apex. Correlated with this appears to be also a marked curvature of the costal margin at the base. The cross-vein system is rather dense. Length of wing 16 to 17 mm.; the measurements of the width as given by Sellards, 4 or 4.5 mm., do not agree with the specimens in the Yale Collection, which are from 4.7 to 5 mm. wide.

If all the specimens with the costal margin thus strongly arched were subimagines, I should be inclined to put the curvature down to distortion during fossilization, especially as Sellards' Figure 6 indicates that some such distortion must have happened to Rs in his specimen. But the Yale Collection contains three specimens agreeing closely with Sellards' figure, and two of these have evidently not been distorted; moreover, one of them is an imaginal wing, which is not likely to suffer distortion as much as a subimaginal wing is, owing to the stronger and stiffer membrane. I therefore feel inclined to uphold Sellards' species.

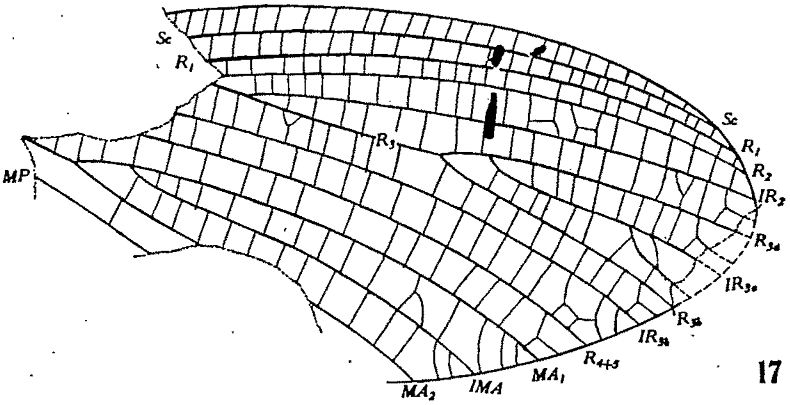

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Fig. 17. *Protereisma arcuatum* (Sellards). Specimen No. 5455.

Specimen No. 5455 a-b shows the distal half of a beautifully preserved imaginal wing with the curvature of the costal margin very clearly marked (Figure 17). *Specimen No. 5456 a-b* shows slightly more of the distal half of a similar subimaginal wing, not quite so wide, and not so well preserved. *Specimen No. 5457 a-b* shows a small portion of the thorax and practically the whole of a pair of wings, fore and hind, of a subimago, but rather poorly preserved; the hindwing is 16 mm. long by 4.8 mm. wide.

Protereisma latum Sellards.

(Fig. 7.)

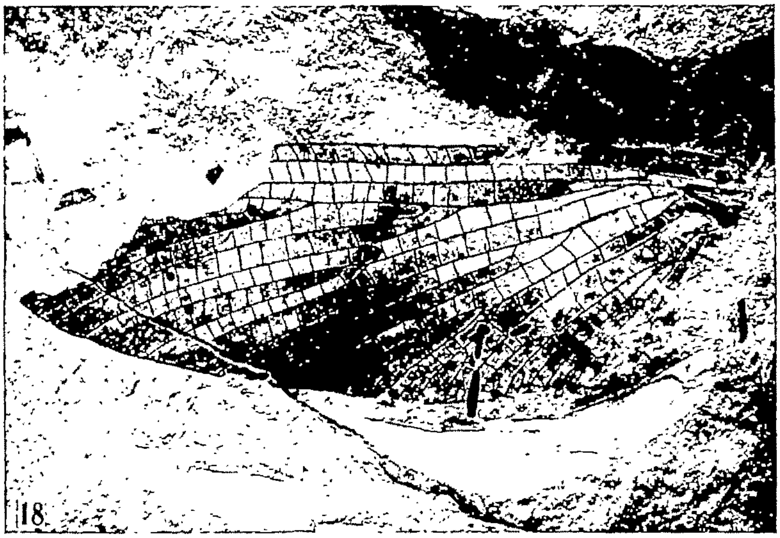
Protereisma latum Sellards, 1907, p. 349.

In many ways this is the most distinct and easily recognizable species of the genus. Reliable specific characters are the large size of the wings, the forewing measuring from 22 to 25 mm. in length, the hindwing about 2 mm. less; their widths also being greater than in any of the foregoing species, ranging from 6.7 to 7.5 in forewing to and from 6.5 to 7.2 mm. in the hind. The costal margin is not as straight as in *P. permianum,* but tends to arch downwards towards the apex more in the manner of that of *P. arcuatum,* especially in the hindwing. Further, the subimaginal wings are distinguished by the possession of a brownish membrane, while in the imagines, though most of the wing is hyaline or subhyaline, there is usually a strongly tinted area of brown near the middle. The costal brace is very strongly formed, the veins and cross-veins strong, the latter not very closely spaced. Both Sc and Cu_2 are very strongly developed at the base, and Sc tends to be somewhat concavely curved basally to the costa, thus pressing the main stem of R very close without fusing with it. The costal margin is serrate throughout.

Type: Holotype specimen in Sellards' Collection, not numbered in his description, showing fore and hind wings lying together, evidently of a subimago.

Specimen No. 1116 shows a very nearly perfect obverse of a fine hindwing, evidently of an imago; *length* 21.5 mm., *greatest breadth* 6.7 mm. The basal two-fifths of the wing is subhyaline, the middle portion rather darkly tinted with brown, the distal portion more lightly tinted. Unfortunately the rock surface is rather uneven, there being a raised boss at about two-fifths from base and a larger raised area near apex, which have somewhat spoilt the even preservation of the wing; also slight damage has been done to the anal area by the scalpel in endeavoring to uncover it completely. The fine black teeth along the serrated costal margin can be clearly seen. In this specimen the separate origins of Rs and MA are beautifully shown, the arch of MA arising somewhat more basad than the origin of Rs from R, and fusing with it almost immediately. A fine vein, almost longitudinally placed, links the anal group of veins with the base of Cu.

Specimen No. 1115 a-b shows, in the obverse impression, a nearly complete forewing, with only the apex and portion of the anal area missing; the reverse is much less complete and consists mostly only of the costal part of the wing. This wing probably belonged to a subimago, but the pigmentation is only shown at all markedly on the reverse impression. *Length* of fragment 20.5 mm., indicating a wing at least 22 mm. long; *greatest breadth* 6.8 mm. The serrate costal margin is well shown, and vein Sc near base is very strong and curved con-



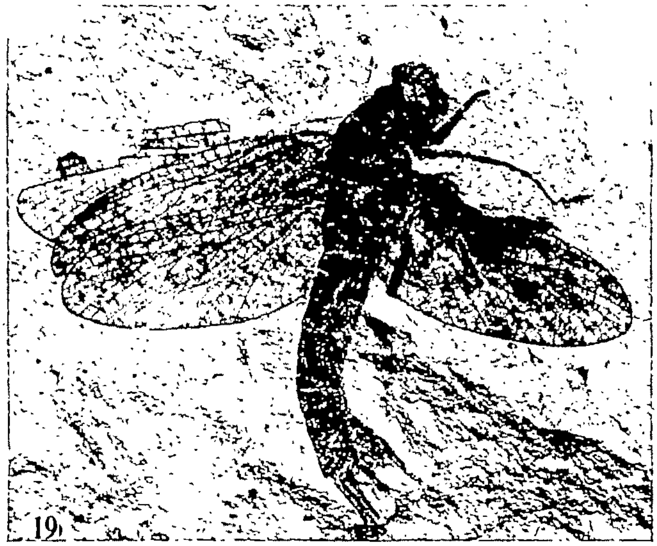


Fig. 18. *Protereisma insigne,* n. sp. Imaginal hindwing. Enlarged photograph of Specimen No. 1112. (Photo by W. C. Davies.)

Fig. 19. *Misthodotes obtusus* (Sellards). Suborder Permoplectoptera, Family Misthodotidae. Enlarged photograph of Specimen No. 1100a, showing practically complete insect. (Photo by W. C. Davies.)

cavely to the costa. The origins and fusion of Rs and MA are also well shown.

Specimen No. 1109 a-b shows the middle portion of a large subimaginal hindwing, with basal and apical portions missing; the obverse impression is broken in two pieces. The brownish pigmentation is clearly shown. *Breadth* 7.2 mm.

Specimen No. 5460 a-b shows the apical two-thirds of a subimaginal wing in the obverse impression, the reverse being more fragmentary. The brown pigmentation is here also quite clearly shown. *Breadth* 7.2 mm.

Specimens No. 5461, 5462 and 5463 are more fragmentary impressions which evidently belong to this species, the first-named being an imaginal wing and the other two subimaginal. No. 5463 shows a fine costal brace.

Specimen No. 5464 a-b shows part of a large imaginal wing rather poorly preserved, and may be provisionally included in this species. *Specimen No. 5452* is a fairly well-preserved imaginal wing with apical portion cut off obliquely, and also appears to belong to this species, though somewhat below normal size.

Protereisma insigne, n. sp.

(Fig. 18.)

This species is based on a finely preserved imaginal hindwing with a small portion of the anal area and a considerable amount of the apical portion missing. *Length of fragment* 25.5 mm., indicating a *total length* of at least 27 mm.; *greatest breadth* 9.0 mm. Veins very strong, especially R and Cu at base. Costal vein well developed but straighter than in previous species. Costal margin with fine black denticles rather widely spaced; posterior margin closely serrated. Cu strongly arched near base; cubito-median Y-vein strongly developed. Third axillary missing in fossil, but the origin of the triad of A_1 beautifully preserved; a bent vein connects Cu basally with A_1. Cross-veins very strong and regularly placed. Membrane slightly tinged with brown, and with a narrow brownish cloud passing slightly obliquely across the wing at about half-way.

Type: Holotype hindwing, obverse only, *Specimen No. 1112* in Yale University Collection.

By analogy with the previous species, the forewing of this species must be in the region of 30 mm. long by about 10 mm. wide, and it is thus, I believe, actually the largest member of the order Plectoptera known, fossil or recent.

Specimens Incertae Sedis.

The following specimens are placed in the genus *Protereisma*, but without any specific determination. Unless otherwise stated, they are fragments of wings:

Nos. 5466 a-b, 5467, 5468 a-b (end of abdomen of male), *5469, 5473 a-b, 5474 a-b, 5475, 5476, 5477, 5478, 5479, 5480, 5481 a-b, 5482, 5483 a-b, 5484, 5485, 5486, 5487 a-b, 5488, 5489, 5490, 5491, 5492, 5493, 5494 a-b, 5495 a-b, 5496 a-b, 5497, 5498, 5499, 5500, 5501, 5502, 5503, 5504, 5505 a-b, 5506.*

Family MISTHODOTIDAE, n. fam.

The mayflies of this family agree with those of the previous family in their general build and in having the fore and hind wings closely similar, the hindwing being slightly the shorter and also the broader near the base. They differ, however, in the following important points:

Wings comparatively broader than in Protereismatidae; the ratio of length to breadth being always less than 3:1 (actual measurements give ratios ranging from 2.9 to 2.6). Size generally smaller, the length of the wing ranging from 9.5 up to 15 mm. at most. Costal and subcostal spaces comparatively broader, with fewer cross-veins more widely and regularly spaced. Sc and R_1 both ending up on costa considerably further from apex than in Protereismatidae. Costal brace formation not so strongly developed, the costal vein weak or obsolescent; the brace itself medium to weak and the angle between the two forks very obtuse. *CuA without any triad*, being either a simple vein or, at most, with only a short terminal twiglet. Cross-vein system generally well developed, but the cross-veins not as numerous as in Protereismatidae. Wings generally of rather more oval shape.

In all the specimens examined by me, the anastomosis of Rs with MA is very complete, and no specimen shows any sign of a separate origin of Rs. I do not, however, include this in the family characters, as it might not prove constant over a larger number than are present in the Yale Collection.

Nine specimens in the Yale Collection belong to this family, which contains only a single genus, *Misthodotes* Sellards.

Genus *Misthodotes* Sellards.

(Figs. 19-22.)

Dromeus Sellards, 1907, p. 351 (nec *Dromeus* Reiche).
Misthodotes Sellards, 1909, p. 151.

Characters as given for the family.

Genotype: Misthodotes obtusus (Sellards).

Horizon: Lower Permian of Kansas.

The three species belonging to this genus may be distinguished as follows:

1. Wings from 9.5 to 12 mm. in length, with well-rounded apices ....2.
Wings about 15 mm. in length, with apex not so broadly rounded.
M. ovalis, n. sp.
2. Wings of imago without any color pattern; those of subimago uniformly dullish sub-opaque ....*M. obtusus* (Sell.).
Wings of imago with two large and more or less rounded blotches of brownish pigment, one near middle and one towards apex.
M. biguttatus, n. sp.

Misthodotes obtusus (Sellards).

(Figs. 19, 20.)

Dromeus obtusus Sellards, 1907, p. 351.

Sellards' short description of the genus and species combined offers very little of actual value to go upon. His type was evidently an imaginal wing, not complete. He states that "the genus is easily recognized by the regularly and uniformly rounded apex of the wing," and gives the measurements of the wing as "length, estimated, 12 mm.; width 4 mm." The wing is stated to be "much smaller than that of any other described species of the family." The only venational character mentioned is that "the middle branch of the sector is deeply forked, the interpolated vein attached to the upper division."

Type: Forewing in Sellards' Collection, not numbered in his description.

Six out of the nine more or less well-preserved specimens of Misthodotidae in the Yale Collection appear to me to belong to this species.

Specimen No. 1100 a-b (Fig. 19): The reverse is a very fine specimen, with head, thorax, abdomen and all four wings practically complete, together with male genitalia, basal portions of tail filaments, and parts of the legs. The specimen is resting partly on one side only, with both forewings and one hindwing folded back normally on the dorsal side, while the other hindwing is spread out on the ventral side, with remnants of two legs lying below it. Parts of both forelegs are preserved in correct position below the head and prothorax. The huge male genitalia are more or less flattened out unsymmetrically beneath the end of the abdomen, with about 2 mm. of the tail filaments *in situ* above them.

Total length from head to end of abdomen 13.5 mm.; *length of abdomen* about 8 mm.; *breadth of head in situ* 2 mm., *of mesothorax in situ* 3 mm., *of abdomen at base* 1.7 mm., *of abdomen at eighth segment* 1.3 mm. Careful drawings of the outlines of the wings *in situ* give the following measurements:

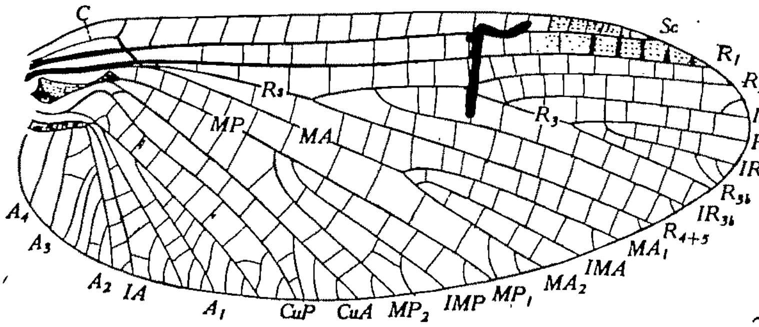


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Fig. 20. *Misthodotes obtusus* (Sellards). Hindwing. Specimen No. 5470, drawn with apex to right. Length 10 mm.

Forewing: Length 11.1 mm., *breadth* 4.3 mm., *ratio of length to breadth* 2.6. *Hindwing: Length* 10.6 mm., *breadth* 3.9 mm., *ratio of length to breadth* 2.8.

Head, thorax and *abdomen* very dark in color, probably subfuscous in life. *Legs* dark above, pale below.

The parts of the *head* cannot be made out with absolute certainty, but one compound eye, more or less collapsed, appears to be situated on the extreme left (Fig. 19); just to the right of it is a small triangular area which appears to correspond fairly closely with the postocular area in the heads of many females of recent mayflies. Traces of a raised epicranial ridge with anterior Y-shaped forking can also be seen, and the positions of three ocelli of moderate size appear to lie in front of this fork. On the anterior margin of the head as preserved there can be seen a small dark appendage which I interpret as the basal portion of the left antenna, consisting of a short scape and somewhat longer and narrower pedicel; the distalia are absent. To the right lies the region of the mouth-parts, which appear to be by no means obsolete, but at any rate partially developed and with distinct suggestions of at least one pair of short jointed palpi, probably the maxillary palpi.

The *thorax* has the three segments all well developed, the prothorax somewhat larger than the head, the meso- and metathorax both very large. This is the only specimen in the Yale Collection in which the thorax is complete, so that the proportions of the three segments can be accurately judged; it will be seen that the mesothorax is only slightly, if at all, larger than the metathorax, and that it does not encroach forward dorsally upon the prothorax.

Legs: The specimen being a male, it is fortunate that a considerable portion of the forelegs is preserved. Coxa and trochanter short but distinct. Fore femur 2 mm. long by about 0.4 mm. wide at base, with a lateral carina running the whole length and separating off a dark dorsal part from a pale ventral part; along or close beneath this carina is a series of short setae directed forwards. Fore tibia about 2.5 mm. long, about 0.2 mm. wide near base, somewhat narrower distally; in one leg the base of the tibia appears to be distinctly swollen dorsally. A long fine line runs the whole length of the tibia, probably marking a slight carina, and carrying a series of short setae directed forwards. The right tibia appears to be complete, but is more or less collapsed at about three-fifths from base; this suggests that the legs in these Permian mayflies were not much stronger than in recent forms, in which the tibiae and tarsi frequently collapse to a greater or less extent soon after death. Tarsi entirely missing.

Wings: Most of the venational characters already mentioned in the definition of the family can be made out in this specimen, but the form of the costal brace and other characters near the bases of the wings are obscured. A point of some interest in phylogeny (see below, p. 268) is the tendency, shown clearly in this and most other specimens of the family, for the middle and apical triads of Rs to approximate towards one another and take on the appearance of a single "pentad." In other words, the middle triad arises well along R_2 while the end triad arises before half-way along R_3. In Protereismatidae, these two triads are always quite distinct. As the position of the triads is variable, it is advisable not to use them in defining family characters; nevertheless, the tendency noted is strongly marked in most Misthodotidae, and as it is very characteristic of recent mayflies, where it undergoes further interesting developments, it must be taken account of phylogenetically.

The specimen is evidently an imago, the wing-membrane being hyaline and the cross-veins quite clearly developed. In the region of the pterostigma, there is slight brownish shading around the cross-veins.

Abdomen with all ten segments clearly preserved in lateral view; the first segment shortest and broadest, the others gradually lengthening and narrowing up to the sixth, but none of them as long as broad; segments 7-10 all well developed, the tenth shorter than the others. A group of three *tail-filaments* (cerci and appendix dorsalis) spring close together from the distal end of segment 10 and are preserved for about 2 mm.; they show numerous narrow annular segments, each armed with short, stiff, black setae. *Male genitalia* exceptionally large, attached along a broad base to segments 8-9, and consisting of a broad forceps-basis and a pair of forceps each about 2 mm. long; the forceps apparently divided into five segments and pointed apically. Between the forceps lies a somewhat asymmetrical but strongly bifid organ which appears to be the penis.

Obverse only represented by two fragments, with part of body and wings.

Specimen No. 5443 a-b shows the head, thorax, part of the abdomen and a small portion of the bases of two wings, and most probably belongs to this species.

Specimen No. 5470 (Fig. 20) is a practically complete reverse specimen of an imaginal hindwing. *Length* 10 mm., *breadth* 3.5 mm. The costal vein is obsolescent, but the brace itself is fairly strong and quite close to the base of the wing. The veins are brownish on a hyaline membrane, except for very slight brownish shading in the pterostigmatic area, as in the previous specimen. The approximation of the middle and apical triads of Rs to form a "pentad" is very well shown in this specimen. The triad of MP arises about half-way along that vein. Cross-veins are mostly clear and regularly spaced. The cubital and anal regions are very faintly preserved but the whole of the venation can be traced out in a good oblique light. CuA has two terminal twiglets; CuP is simple and slightly waved; A_1 has a large triad developed from near the base; IA_1 lies rather close to A_2; A_2 has a series of posterior descending branches, and is followed basally by two simple axillary veins descending transversely from the third axillary. The posterior basal margin of the wing is very broadly rounded.

Specimen No. 5471 a-b represents a hindwing of a subimago only moderately well preserved and with part of the anal area missing. The measurements, length 10 mm. and breadth 3.5 mm., are those of an average hindwing. The cross-veins are very faint on a dull sub-opaque membrane. The apical triad of Rs is less well developed than usual. The reverse specimen is nearly complete, the obverse fragmentary.

Specimen No. 1117 a-b is a very poorly preserved subimaginal specimen, provisionally assigned to this species, showing head, thorax and most of the abdomen, as far as the base of the male genitalia, and outlines of the wings, very faintly impressed on the rock. It appears to be of slenderer build than Specimen No. 1100; but, unlike it, is preserved in absolutely lateral view, which may perhaps account for the difference in the apparent breadths of thorax and abdomen. The femora of one fore, middle and hind leg are preserved, and also the basal portion of a fore tibia.

Specimens No. 5459 and *5465 a-b,* both very poorly preserved, may be provisionally included in this species.

Misthodotes biguttatus, n. sp.

(Fig. 21.)

This species is based upon an imaginal hindwing, beautifully preserved, but slightly damaged by the chisel basally, so that the costal brace is not preserved. *Length* 11.5 mm., *breadth* 4.3 mm. The veins are brown upon a hyaline membrane, but there are two very clearly marked rounded or oval patches of brown pigment; one of these, about 1.4 mm. across, lies near the middle of the wing, just distad from the origin of the basal triad of Rs, while the other, about the same size but slightly more oval, lies towards the apex, covering the origin of the apical triad of Rs. Cross-veins rather widely spaced, there being only about twelve in the subcostal space. The approximation of middle and apical triads of Rs to form a "pentad" is well shown in this specimen.

Type: Holotype, hindwing, *Specimen No. 1122* in Yale University Collection. Obverse only, with apex to left.

This species may be distinguished from *M. obtusus* (Sell.)

not only by the somewhat larger size and distinct color-pattern of the wing, but also by the differently shaped and somewhat less widely rounded apex, by the comparatively wider costal and subcostal spaces and the somewhat more widely spaced and less numerous cross-veins.

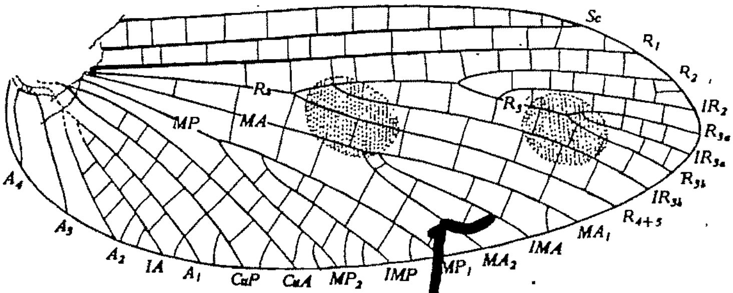

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Fig. 21. *Misthodotes biguttatus,* n. sp. Hindwing. Specimen No. 1122, drawn with apex to right. Length 11.5 mm.

Misthodotes ovalis, n. sp.

(Fig 22.)

This fine species, the largest yet discovered in this family, is based upon a well-preserved imaginal forewing. *Length* 15.0 mm., *breadth* 5.0 mm. Apex not broadly rounded (the extreme tip is missing) but only so as to give an elongate oval form to the wing. Sc and R_1 both ending well before apex, and both costal and subcostal spaces narrowing markedly at their ends. Costal vein faint, but costal brace well formed, close to

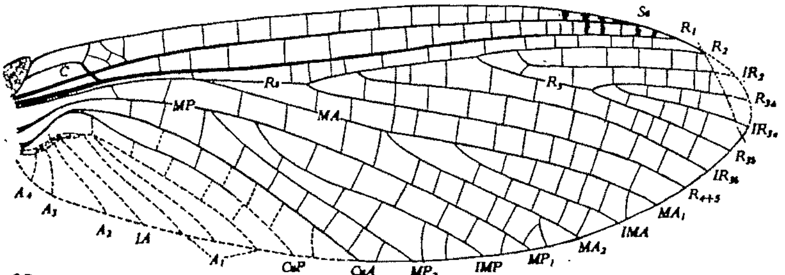

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Fig. 22. *Misthodotes ovalis,* n. sp. Forewing. Specimen No. 1118. Length 15 mm.

base of wing. Rs and MA are strongly fused to a distance about twice as far from base as costal brace. Basal triad of Rs arises closer than usual to MA; middle and apical triads of Rs quite distinct, though apical triad arises before half-way along R_3. Triad of MA well developed, arising near middle of wing; that of MP very long, arising below origin of MA from Rs. Cross-veins fairly widely spaced, but closer and more numerous in costal and subcostal spaces in region of pterostigma, where most of them also are suffused with brownish pigment. Veins mostly pale brownish, but where freshly uncovered near base, nearly black.

Type: Holotype forewing, Specimen No. 1118 a-b in Yale University Collection; obverse and reverse both well preserved; obverse with apex to left. *Allotype forewing, Specimen No. 5472 a-b,* also very well preserved, but lying on a somewhat irregular rock surface which tends to obscure the correct outline of the wing; apex missing. In this specimen, the veins at the base are darker than in the holotype; most of the anal area is preserved, and is used for the restoration (dotted lines) in Figure 22.

EVOLUTION OF RECENT TYPES OF THE ORDER PLECTOPTERA.

The representatives of the order Plectoptera living at the present day may be distinguished by the subordinal name Euplectoptera, defined by the reduction of the hindwing to a size much smaller than the fore and by correlated changes in the comparative sizes and structure of the meso- and metathorax.

There can be no doubt whatever that the Euplectoptera are the direct descendants of the Permoplectoptera; for there is not a single character found in the latter which fails to agree with our conception of an archetype for the Euplectoptera before the reduction of the hindwing began. All the characters of the head, thorax, abdomen, legs and tail-filaments so far revealed in the fossil Permoplectoptera agree admirably with what is required in such an ancestor. In the wing-venation, the structure of the costal brace-vein offers a rational and simple explanation of the present homologous brace-vein structure in the Euplectoptera, through fusion of the true costal vein with the costal margin of the wing. The system of triads in Permoplectoptera and in Euplectoptera is exactly the same, and the main veins and their branches in the two suborders can be homologized throughout in the forewings, while the venation of the hindwing in Euplectoptera is quite rationally explained as a direct reduction-form from the forewing type.

If this position be accepted, we may now ask whether it is possible to indicate either the Protereismatidae or the Misthodotidae as the actual ancestors of the Euplectoptera. This is a more difficult question, but we ought to attempt a solution. If a key is to be found to it, surely the venation alone can supply it! Let us, then, examine it in closer detail:

(1) *The costal brace:* In this character the Misthodotidae are at a more reduced stage than the Protereismatidae. But the simplification of the brace in the former family is being brought about by the obsolescence of vein C, leaving the forked distal end of the structure as an obtuse-angled brace. Quite conceivably this could have evolved into the Euplectopteran brace-vein by straightening out of the obtuse angle. This, however, will not explain the marked thickening of the costal margin basad from the brace-vein. The logical explanation for this is that the original costal vein, C, instead of becoming obsolescent as in Misthodotidae, has moved gradually closer to the costal margin and finally fused with it. The fossil species *Protereisma elongatum* (Sell.) exhibits this movement already in Permian times; so that we may readily assume that the ancestors of the Euplectoptera were some group of forms possessing a similar tendency.

(2) *The form of Sc and R_1:* In all Euplectoptera, Sc and R_1 run almost or quite to the apex of the wing. In the Protereismatidae the condition is much the same as this, but in the Misthodotidae these veins are distinctly shorter. Further, in the forewings of Euplectoptera the costal space is wide basally but becomes narrow very rapidly, remaining narrow throughout; the subcostal space is narrow basally but widens somewhat after the brace-vein and then narrows again distally. This corresponds more closely with the condition found in the Protereismatidae than in the Misthodotidae, where both spaces are markedly wider; only in one species, *Misthodotes ovalis*, n. sp. is there any marked narrowing of these spaces even distally. In this character, then, the ancestor most clearly indicated is the family Protereismatidae.

(3) *The form of the triads:* The families Protereismatidae and Misthodotidae differ in three[1] important points as regards their triads:

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[1] As *both* families agree with recent mayflies in having the middle triad of Rs normally a metatriad, while other triads are normally protriads, this character is not considered here.

(a) In the tendency of the Misthodotidae to amalgamate the middle and distal triads of Rs into a single "pentad" formation. Recent Euplectoptera show also this same tendency, often carried considerably further by the switching over of the original basal connections of the interpolated veins, so that it would be almost impossible to disentangle the elements of the two original triads without the fossil wings to guide us. In this respect, the Euplectoptera resemble the Misthodotidae more than the Protereismatidae.

(b) In the more basal origin of the triad of MP in Protereismatidae as compared with Misthodotidae. In this character, recent forms obviously resemble the Protereismatidae.

(c) In the presence of a distinct triad on CuA in the Protereismatidae and its absence in Misthodotidae. With the single exception of the puzzling genus *Baëtisca,* the forewings of recent mayflies have the vein CuA always branched in some manner or other; but this branching can seldom be interpreted as an original triad. Hence we are faced with the question whether the various forms of branching now found on CuA have been evolved from an original triad, or from an unbranched CuA of the type found in Misthodotidae. Both lines of evolution are quite conceivable. If we could decide clearly in favor of one or the other, the character in question is so striking that it should outweigh all the other evidence combined. But I find myself unable to decide. On the one hand, in spite of the fact that most of the archaic family Siphlonuridae have CuA with a posterior pectinate series of branches instead of a triad, there appear at first sight to be quite a number of genera in the Lepthophlebiidae and Baëtidae which have true triads on CuA. But when we come to analyze these formations and to try to trace them back through related genera to their origins, I cannot find a single one of which I can say definitely that I am satisfied that it is a true original triad. This question could not possibly be solved without a very careful analysis of closely related genera, and, in particular, a meticulous study of the modes whereby the reductions evident in the Baëtidae and related groups have been brought about. Further, there is the very awkward fact that *Baëtisca,* in many ways an archaic type, has a forewing with an unbranched CuA. If this is the primitive condition, then it seems that we should admit that the Euplectoptera have come from a stock resembling the Misthodotidae in the condition of CuA. But it may equally well be a secondary reduction, due to growth and encroachment of vein A_1 on the territory originally occupied by CuA and

CuP, in correlation with secondary enlargement of the hindwing. For one sees that, in connection with the tornus or angle of the posterior margin of the forewing, vein A_1 occupies in *Baëtisca* exactly the same position as vein CuA does in the other genera of Siphlonuridae. Further, the hindwings of all recent mayflies, with the sole possible exception of the very richly-veined *Campsurus,* have CuA without any triad or definite scheme of branchings. This, again, may be the ancestral condition, as in Misthodotidae, or it may be due to the reduction in size of the hindwing, which has at any rate affected the triads of Rs and M, and might, therefore, have eliminated that of CuA, if it originally existed. Clearly, then, the question has for the present to be left undecided.

To sum up the above evidence, it would appear to me that we cannot state definitely that either the Protereismatidae or the Misthodotidae were the actual ancestors of recent mayflies. The balance of evidence favors the Protereismatidae, with which modern mayflies agree in the character of the subcostal and radial veins, the basally placed origin of the triad of MP and also in the most probable mode of evolution of the brace-vein. The one character which favors the Misthodotidae is the tendency of the middle and distal triads of Rs to come together into a single "pentad" formation. The most important character of all, that of the presence or absence of an original triad on CuA, remains still very much in doubt.

For what it is worth, the evidence of *size* may be given some weight. It is fully agreed that the largest of existing mayflies, and more especially the Siphlonuridae, exhibit the greatest number of archaic characters. So the ancestors of the Euplectoptera must have been comparatively large forms. In so far as this has any value, it suggests that the Protereismatidae were about the right size for the ancestral group of the Euplectoptera.

A fairly reasonable, though somewhat tentative, conclusion would be that the actual Permian ancestors of recent mayflies belonged to the Permoplectoptera in the broad sense, but are not represented by either of the families studied in this paper. The evidence, on the whole, appears to indicate an ancestral family type somewhat intermediate between the Protereismatidae and the Misthodotidae, but definitely closer to the former than to the latter.

In concluding this paper, I wish to express my thanks to Mr. W. C. Davies, Curator of the Cawthron Institute, Nelson, N. Z., for the excellent photographs reproduced in Figures 18 and 19, and to Mr. A. L. Tonnoir for that reproduced in Figure 7.

POSTSCRIPT.

Shortly after the completion of this paper, I received from Professor A. B. Martynov a letter dated March 31st, 1931, from Petrograd, and written in reply to a previous one of my own, dated Jan. 25th, 1931, in which he stated that he had gone once again into the problem of the interpretation of the venation of the wings of Plectoptera, and had read my paper of 1923 on this subject, and now accepted my interpretation of the limits and composition of M and Cu in this order. He says in this letter:

> "I am very obliged to Dr. F. Carpenter for the translation of old (*sic*) paper on wing venation of Odonata and Agnatha, but at present this paper becomes, indeed, 'old fashioned.' When I wrote this paper, your very important article on the wings of Protereisma was unknown to me (1922), therefore my interpretation of the venation in mayflies proved to be incorrect, as concerning M and Cu. At present I accept your new(and of Lameere) interpretation of the venation in Agnatha."

His inclusion of the words "and of Lameere" in parentheses indicates that he agrees with my interpretation of the limits of Rs and MA as well as of M and Cu. In other words, he would now be in entire agreement with the argument as set forth in the present paper, except, perhaps, regarding details as to the interpretation and notation of the anal veins.

Nevertheless, it seemed to me advisable to retain the argument as here set out, leading to the conclusions on which Professor Martynov and myself are now agreed, so that the historical development of the ideas about mayfly venation may be preserved completely in our records.

While unpacking and listing two very large packages containing fossils sent by the British Museum, which I had had no opportunity to examine since leaving New Zealand, I found a small box carefully packed away in the middle of one of the larger ones. This box contained two fine specimens of Mayfly wings belonging to the genus *Protereisma,* from the Yale University Collection. It is greatly to be regretted that they were overlooked when the present paper was written.

Specimen 1009 contains two wings of *Protereisma permianum* Sell. One of these is a very nearly complete hindwing, reverse impression, apex to left, measuring 17.5 mm. long by 5.8 mm. wide, with brace-vein and basal part of anal area indistinct. This wing was figured with apex to right in a previous paper (Tillyard, 1923, p. 145, Fig. 1a). Just to left of it lies an incomplete wing with anal area and much of apical portion missing; this appears to have been a forewing of the same insect, and is also a reverse impression.

Specimen 1023 is a large hindwing, reverse impression, apex to right, measuring 22.0 mm. long by 6.2 mm. wide, practically perfect, with a strong costal brace-vein about 3 mm. long, and with apex not so broadly rounded as in *P. permianum* Sell. The costal margin is serrated throughout its length, and in other characters it appears to agree with *P. latum* Sell., though the usual brown pigment of that species is lacking. It would appear to belong to a subimago.

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Canberra, F. C. T.

SCIENTIFIC INTELLIGENCE.

CHEMISTRY AND PHYSICS.

Lehrbuch der Physiologischen Chemie; by EMIL ABDERHALDEN. Sixth Edition. Pp. viii, 852; 24 text figs. Berlin, 1931 (Urban and Schwarzenberg; 40 RM., bound 42 RM.).—This is a completely revised edition of a textbook that has long enjoyed popularity among students of biological sciences. The volume is not a mere compendium of the conventional sort. It presents the problems as well as the established contributions of physiological chemistry. Wherever doubt arises, liberal references to the literature of the debated topic are presented. Its up-to-date character is indicated by the fact that some of the citations refer to papers printed during the year in which the book was published (1931). American papers are not overlooked in the way that has occasionally happened in European textbooks. It would be futile to attempt in this brief notice to review even one of the 38 lectures that cover the entire range of the chemistry of living matter and the processes in which it may be involved. Unlike many—perhaps even most—books on biochemistry, Abderhalden's textbook does not fail to stress the functional aspects of the subject. In this respect it is a veritable presentation of chemical physiology, including the newer aspects of the science of nutrition. The metabolism of energy as well as of matter is included. The book is a volume of almost encyclopedic proportions and character. L. B. M.

The Atomic Weight of Xenon: The atomic weight of xenon as given in the International Tables of Atomic Weights and based upon the determination by Moore in 1908 is 130.2. The accuracy of this value was first called in question by Aston in 1922, who deduced from his examination of the lines in his mass spectrograph a value of 131.3. As his measurements for other elements, notably, mercury, zinc, molybdenum, chromium, and tin, give values which accord very closely with the best chemical determinations, it has appeared likely that the atomic weight of xenon and also of krypton were in error.

The question has recently been examined by R. WHYTLAW GRAY, H. S. PATTERSON and W. CAWOOD by a method in which the balancing pressure of oxygen and xenon were compared by means of a sensitive buoyancy balance. The main difficulty with such a balance is to ensure that the zero point remains really constant over long periods. Any form of point, or knife edge, has been found to cause minor fluctuations often difficult to detect, which render the instrument valueless for accurate work. These authors finally adopted the principle of a horizontal fibre suspension. The balance itself consists of a beam of silica rod, 1 mm. in diameter, swinging between two horizontally stretched quartz fibres. A buoyancy bulb about 1.5 cm. in diameter was suspended from one end of the beam by a quartz fibre. To the other end is attached a quartz microscope cover glass and a small counterpoise. This cover glass serves the purpose of providing a compensation for adsorption so that the surface moments on each side of the beam are nearly equal. The balance is designed for use as a null point instrument, its zero being defined by a fixed point attached to the frame in close juxtaposition to a fine pointer on the end of the beam. The whole balance was of such small dimensions that it could be contained in a cylindrical glass tube of about 25 c.c. capacity.

Extreme care was used in fractionating the gas until the changes in density were less than the limits of experimental error. The purity of the xenon having been established, the ratios of the balancing pressures of oxygen and xenon were then determined with the final sample of the fractionated gas at pressures of xenon at about 153 mm. and 80 mm. The resulting ratios were extrapolated to zero pressure and the limiting ratio was found to be 4.1020.

This gives the atomic weight of xenon as $4.1020 \times 32 = 131.26$ with an error which the authors do not think can exceed $\pm .01$, a result which agrees remarkably closely with the latest determination of Aston who found $131.27 \pm .04$. They are in fact identical within the limits of experimental error.

Proc. Roy. Soc. A 134, 7, 1931.

The Principles of Electricity; by LEIGH PAGE and NORMAN ILSLEY ADAMS, JR. Pp. xi, 620; 319 figs. New York, 1931 (D. Van Nostrand Company, $4.25).—Of all general books on Electricity and Magnetism which have appeared up to the present, this one seems to us to be the best. It covers the whole field starting with the simplest principles, is thoroughly modern, being based on the electron theory, and is sufficiently mathematical to meet the requirements of most advanced students. Not only does it present an adequate theory of most phenomena but also follows these discussions with an account of the most important measuring instruments whose theory is derived from the principles discussed. In the former category may be mentioned metallic conduction, electrolysis, thermo-electricity, thermionic emission, the Hall effect, diamagnetism, etc. In the latter, the magnetometer, the Wheatstone, Kelvin, Carey-Foster and Callendar and Griffiths bridges, galvanometers, the fluxmeter, and various A.C. bridges.

Students of engineering as well as students of physics will be interested in the treatment of A.C. circuits, coupled circuits, filters, and the chapters on electro-magnetic waves and high frequency oscillations.

This is a book that will appeal to every graduate student of physics. F. E. B.

The Physics of High Pressure; by P. W. Bridgman. Pp. vii, 398; 87 figs. New York, 1931 (The Macmillan Company).—In this work the author has carefully reviewed the work of others and summed up his own contributions to high pressure phenomena, a work in which he has been engaged for twenty-five years.

The initial chapter gives a historical survey of the subject in the large. This is followed by chapters on the general technique in which the author tells how by his discovery of the principle of unsupported area he has been able to solve the problem of a packing which would support the highest pressures and also how he succeeded in the measurement of high pressure by the change of the electrical resistance of a manganin wire when subjected to pressure. A chapter also is devoted to the rupture due to high pressure. The body of the book, comprising some nine chapters, is occupied with a quantitative description of a large number of high pressure phenomena which may ultimately be expected to have some theoretical significance, such as P. V. T. relations in fluids, the compressibility of solids, melting phenomena under pressure, polymorphic transition under pressure, and the changes in electrical resistance, in thermo-electric properties, in thermal conductivity, in viscosity and various miscellaneous effects of pressure.

This work is a valuable contribution to a field in which comparatively few books have appeared. F. E. B.

Atomtheorie und Naturbeschreibung; by Niels Bohr. Pp. 77. Berlin, 1931 (Julius Springer, RM. 5.60).—This pamphlet embodies a discussion of the philosophical principles underlying our conceptions of atoms and their interpretation on the quantum theory. It contains four essays. The first, prepared as an address at the mathematical congress held in Copenhagen in August, 1925, is entitled Atomic Theory and Mechanics; the second is an extension of a lecture delivered at the International Physics Congress at Como in September, 1927, and treats the Quantum Postulate and the Newer Development of Atomistics; the third is an article which was contributed to the journal, *Naturwissenschaften,* in celebration of Planck's 50-year jubilee in June, 1929, and is upon the Working Quantum and the Description of Nature; the fourth is an expanded lecture presented by the author at a Scandinavian assembly of scientific investigators in 1929 in which he endeavors to give on the background of the preceding articles, a view of the position of atomic theory in any description of nature.

F. E. B.

Johann Kepler, 1571-1630. Pp. xii, 133, with frontispiece, 2 figs. and 1 plate. Baltimore, 1931 (The Williams and Wilkins Company, $2.50).—One wonders in reading the life of Kepler, how, in the atmosphere of superstition, mysticism, and speculation in which he lived, he should have been able to draw such a happy solution of the mystery of planetary motion as he embodied in his three famous empirical laws. It seems to have sprung from his unequalled zeal for mathematical calculation and his faith in the remarkably accurate observations of Tycho Brahe.

This book is a memorial volume containing three addresses on the occasion of the commemoration of the tercentenary of Kepler's death, held at Cleveland, December 31st, 1930. The first, by W. Carl Rufus, treats of Kepler as an astronomer, the field in which he won his greatest renown. The second traces his career as a mathematician and reviews his contributions, few yet substantial, to the infinitesimal calculus, to logarithms, and to geometry. The third attempts an evaluation of the place of mystical ideas in the mind of Kepler.

Frederick E. Brasch in addition has compiled expressly for this volume a comprehensive bibliography of 47 pages of Kepler's writings with historical interpretations of their content by well-known authorities.

This brief survey of the life and work of Johann Kepler which we owe to the History of Science Society will clearly aid in a better understanding of one of the first of our great modern astronomers and mathematicians. F. E. B.

Elektrophorese, Elektro-osmose, und Elektrodialyse in Flüssigkeiten; by P. H. PRAUSNITZ and J. REITSTÖTTER. Pp. xii, 307; 54 figs. Dresden and Leipzig, 1931 (Theodor Steinkopff, 18.50 RM., 20 RM., bound).—By electrophoresis is meant the wandering of colloids toward the anode of a cell, and by electro-osmosis, the transport of water, or watery solutions, through capillaries, or through capillary systems of diaphragms or membranes. In the case where an electrolyte under the influence of an electric current is assisted to pass through a diaphragm without other essential processes occurring the process is termed electrodialysis.

The work above-named seeks to bring into conjunction all scientific discoveries and observations, together with all directions of research and ways of working, so as to give an objective picture of the development of this branch of inquiry in the field of the electro-chemistry of colloids.

In addition, the authors have devoted about 100 pages to technical applications with especial consideration of patent literature and followed it by a full bibliography and list of patents.

F. E. B.

Einführung in die Theorie der Wellengleichung; by HARRY SCHMIDT. Pp. vi, 146; 16 figs. Leipzig, 1931 (J. A. Barth, RM. 11.70).—This book is intended as an introduction to the treatment of problems in characteristic values (Eigenwerten) in partial differential equations and so presented that, without making too great demands upon his analytical skill, it should give the reader confidence in the indispensable mathematical methods necessary to an understanding of Schrödinger's wave mechanics.

In the first four chapters the pertinent conceptions and theorems are developed in detail and applied to such classical physical problems as the vibration of strings, of membranes and of fluids. In the last chapter the Schrödinger wave equation is derived in an elementary way and applied to the special case of a rotator and to the hydrogen atom.

This is a book which will interest advanced students of physics.

F. E. B.

GEOLOGY.

The Geology of Central Sutherland; by H. H. READ. Pp. viii, 238; 5 pls., 13 figs., with Maps 108, 109. Memoirs of the Geological Survey of Scotland. Edinburgh, 1931 (4 shillings sixpence).—A detailed explanation of Sheets 108 and 109 of the sectional Geological Map of Scotland, completing the descriptions of the geology of the Scottish Highlands north of Inverness. The area includes the famous northern peaks of Ben More Assynt, Ben Loyal, the Griams, Morven and Scaraben. The opening chapters summarize the geology of the region. Short chapters dealing with the Lewisian, Torridonian and Cambrian on the west and with the Old Red Sandstone and Jurassic on the east link the present memoir with those already published. The main feature is, however, the description of gneisses of Lewisian type which occur as apparently integral parts of the Moine Series and of the injection complexes of Loch Choire and Strath Halladale. The injection complexes are developed on a grand scale and exhibit a wide variety of petrographic types.

A short account of Pleistocene events in this region, which involved ice-sheet glaciation followed by the later local development of valley glaciers, concludes the volume. R. F. F.

The Geology of the Whitehaven and Workington District; by T. EASTWOOD, E. E. L. DIXON, S. E. HOLLINGWORTH, and BERNARD SMITH. Pp. xvii, 304; 8 pls., 27 figs. Memoirs of the Geological Survey of England and Wales. London, 1931 (6 shillings).—An explanation of the geology of the district covered by the New Series Ordnance Map Sheet 28. The stratigraphy discussed in detail includes the slate and granite complex of the Lake District, Carboniferous limestone, Millstone Grit, productive Coal Measures of the Whitehaven Coalfield, the red Permo-Triassic sandstones of St. Bees, and a full sequence of Pleistocene glacial deposits. R. F. F.

Bermuda during the Ice Age; by ROBERT W. SAYLES. Proceedings of the American Academy of Arts and Sciences, Vol. 66, (November) 1931, pp. 381-467; 13 pls. and 18 text figs.—In this short but very well-balanced essay, the writer draws from the work of earlier investigators and adds a quantity of new material based on his own studies, to form a complete picture of the geology of Bermuda. The island is built on a broad platform of pre-Pleistocene volcanic material, upon which rest eolian limestones interbedded with five ancient soils and local marine limestones. Stratigraphic evidence indicates that sea-level has stood both higher and lower at various times in the past than at present. The hypothesis is advanced that the several eolian horizons accumulated during the times of eustatically lowered sea-level attendant upon the Pleistocene ice advances, when high southwesterly winds following glacially displaced storm tracks swept across newly exposed marine flats floored with calcareous material. Conversely, the soil horizons are thought to have been formed during the interglacial times of high sea-level. The author finds a good agreement between the succession of alternating eolian limestones and ancient soils of Bermuda, and the latest American fourfold succession of glacial and interglacial stages. R. F. F.

The Paleontology of Kentucky; edited by WILLARD ROUSE JILLSON. A symposium from the separate manuscripts of Roy L. Moodie, Arthur C. McFarlan, August F. Foerste, T. E. Savage, J. Marvin Weller, Wm. C. Morse, J. K. Roberts and C. L. Cooper. Pp. 469; 79 pls. and frontispiece, 33 text figs. Kentucky Geological Survey, Series Six, Vol. 36. Frankfort, 1931.—Eight collaborators have joined Dr. Jillson in the difficult task of presenting to the citizen and student of the state the chief fossils which he may find in Kentucky. They have tried to enable him to identify the many species and to recognize the several geologic formations by the entombed fossils. Of necessity, therefore, the treatment is technical, involving brief descriptions of the rock formations and notes on their characteristic faunas, as well as brief descriptions of many species. The arrangement is stratigraphic, separate chapters being devoted respectively to Ordovician faunas, Silurian faunas, etc., each written by a separate author.

As a whole, the book suffers from the lack of organization and of unity of treatment. In the Ordovician, Pennsylvanian and Pleistocene chapters all species are described, but in the other chapters none. The Pennsylvanian alone presents several new species. C. O. D.

A Preliminary Report on the Foraminifera of Tennessee; by JOSEPH A. CUSHMAN. Pp. 116; 13 pls. State of Tennessee, Department of Education, Division of Geology, Bulletin 41. Nashville, 1931.—A description, with illustrations, of the foraminifera of six richly fossiliferous localities in the Cretaceous strata of Tennessee. Contrary to expectation, the Selma chalk was found to have abundant and finely preserved foraminifera. The faunas studied permit correlation of different parts of the Selma with definite horizons in the Cretaceous section of Texas. Ten of the species and three varieties are new.

In the beautiful plates of this volume, Dr. Cushman continues to set a standard for others to emulate. C. O. D.

Accessory Minerals of Crystalline Rocks.—The National Research Council has announced a new Committee on Accessory Minerals of Crystalline Rocks to study the nature of such minerals, their variation in time and space in igneous bodies and metamorphosed masses and their distribution in sediments. Such studies in the past have shown that some igneous masses have rather characteristic accessory minerals which may be useful in some cases in determining the relationships between isolated outcrops, but very little is known regarding the differences in different parts of a single intrusion or in successive intrusions from a single magmatic source. The committee will attempt to correlate work now in progress and stimulate further study along these lines. At present the committee consists of E. S. Larsen of Harvard, J. C. Reed of the U. S. Geological Survey, J. E. Stark of Northwestern, A. C. Tester of Iowa, A. N. Winchell of Wisconsin (chairman), and J. F. Wright of the Canadian Geological Survey.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

The Conquest of Old Age: Methods to effect Rejuvenation and to increase Functional Activity; by PETER SCHMIDT. Pp. xvii, 301; 40 plates. Translated from the German by Eden and Cedar Paul. New York, 1931 (E. P. Dutton and Company, $5.00).—Schmidt's book contains a most interesting and comprehensive discussion of the effects of the Steinach operation. The first portion of the book includes the history of the subject, practical applications, and a rather imposing series of case histories of the author and those of other workers in this field.

Schmidt refutes the criticism that the effects of the operation are those which could be produced by suggestion. The objective results are presented in terms of improvement in the condition of the hair, skin, eyes, and blood pressure as well as in the sexual life. At the same time the possibility is stressed that irreparable damage, for example, "arterio-scelerosis," cannot be remedied. The operation rather produces a delay in the approach of old age. It permits later life to continue on a more active plane and may even prolong life. Certainly, the span of life is not shortened if the patient does not over-exert himself.

The best age for rejuvenation in woman is at the climacteric. In man the time is more variable and must be decided after the clinical examination of the individual case.

The book concludes with a general description of the importance of the internal secretion of the gonads in preventing disabilities of old age, for it is the ambition of the author to prolong the span of human functional capacity. H. E. HIMWICH.

The Use of the Self; by F. MATTHIAS ALEXANDER. Pages xix, 143. New York, 1932 (E. P. Dutton and Co., $2.00).—The first third of this book is a description of the long and difficult analysis made by Mr. Alexander in the effort to discover what fault in the use of his vocal organs made it impossible for him to give public readings without growing hoarse. He discovered the fault—that he was putting his head back. He discovered that he could not cure this fault by resolving to put his head forward; for when he tried to carry out the resolution he saw in a mirror that his head went back according to its old habit. He thus became aware of his "sensory untrustworthiness." Trustworthiness was finally restored by a technique of three elements: (1) giving himself repeatedly the reasoned-out directions for the series of acts; (2) inhibiting the impulse to act; (3) deciding afresh how the directions should be used. This procedure is considered contrary to all the procedure in which man's processes have been drilled throughout his evolution.

The nature of the cure for wrong habits is illustrated by contrasting it with the common advice to "keep your eye on the ball." This advice, says Mr. Alexander, results only in failure. A man can develop a sure stroke only by uprooting "the primary desire to feel right"; for he has no norm by which to gauge his feeling right. He must first stop trying to make a good stroke and must develop the "means whereby principle" of building up "a new direction of the use of his mechanisms." In a similar way stuttering can be cured.

John Dewey, the most famous American philosopher, has taken instruction as a pupil of Mr. Alexander and testifies to its profound efficacy: "It is a discovery which makes whole all scientific discoveries and renders them available for human use in promoting our constructive growth and happiness." He is convinced that the Alexander therapy is of fundamental importance for all education and medicine.

We who have not been pupils have to remain in the dark as to this mysterious "means whereby," since the book does not describe one detail of the new use of mechanisms which is set going in the organism of a poor speaker, or a poor golfer, or a stutterer.

HENSHAW WARD.

A Guide to the Spring Flowers of Minnesota; by CARL O. ROSENDAHL and FREDERIC K. BUTTERS. 6th ed. Pp. xviii, 89; with plates. Minneapolis, 1931 (University of Minnesota Press; $1.00).—The present work is one of the best elaborated and successful attempts to meet the student demand for a brief and cheap handbook for the naming of species flowering during the academic year. The current edition follows the plan of its predecessors, but includes some sixty more species and adds (with a corresponding increase of usefulness) generic descriptions and three full-page plates illustrating types of inflorescence, floral structure and fruit. These plates bear acknowledgments of the sources of the drawings used; in some other illustrations taken over from previous editions, no such acknowledgment is made, though it is obviously as much needed. The introductory matter dealing with the relation of floral development and methods of pollination and with phylogenetic theory is particularly clear and good, and avoids the pit into which phylogenists have been known to fall—that of stating as if it were fact what is really scientific conjecture. An unusual feature is a key to double-flowered garden forms.

C. A. WEATHERBY.

The Temple of the Warriors at Chichen Itzá, Yucatan; by EARL H. MORRIS, JEAN CHARLOT and ANN AXTELL MORRIS. Quarto. Two volumes. Text, pp. xix, 485. Also 170 plates separately bound. Carnegie Institution of Washington. Publication No. 406 ($20.00).—Chichen Itzá was conspicuous among the great capitals of the New Maya Empire. According to the known records the Itzá had first settled Chichen shortly before 530 A.D. In 668 A.D. the city was abandoned; but the Itzá re-established themselves at Chichen in 944 A.D. The Temple of the Warriors stands in the northern end of the city. It was in an advanced stage of ruin when the authors began their work on it in 1925.

The temple complex was found to be composed of a pyramid with a temple on its summit, a long rectangular columned hall flanking the western base and the north range of the Group of the Thousand Columns. The book is divided into three parts: the first by Mr. Morris on a Description of the Temple of the Warriors and Edifices Related Thereto; the second by J. Charlot on Bas-Reliefs; and the third by Mrs. Morris on Murals.

A mature forest covered the Temple of the Warriors when in 1923 Dr. Morley began the clearing of the area. There is no way of telling on how many previous occasions the area had been cleared. At the time of the visit by Stephens in 1841, Chichen Itzá was a cattle ranch. Forty-seven years later, Maudslay felled as much of the timber as his purposes demanded. A good many resisting stumps remained from this clearing and there were also a few large trees, which showed that deforestation had not been complete.

Morris describes the western terrace which was the area where excavation was begun. He describes the serpent columns, the north and south terraces, clearing of the temple interior, condition of the altar, finding of frescoes, clearing of the north and south sides of the pyramid, the statuette standard bearers, dais and sacrificial stone, the buried Chac Mool, concrete foundation for the temple, etc. According to Morris the procedure followed by the masons can be reconstructed almost as surely as if one had watched them at work. Considerable space is given to chronological sequence and to materials and methods of construction. Chichen masons seem to have relied solely on the human eye as a leveling instrument.

Charlot's contribution deals with the bas-reliefs. There are 337 panels, each comprising a life-size human representation and two decorative motives. The author treats successively of the masks and atlantean figures of the decorative panels; body-color, tattooing and mutilation in the human representations; head-dresses, wigs, ear and nose ornaments; necklace, shoulder-cape and breast ornaments; sleeve and wrist ornaments; belts, leg and foot gear; cloaks, weapons and accessories, etc. The human types fall under four heads: warrior, priest, God impersonator and miscellaneous personages.

The style of the group including the Chac Mool Temple, the Warriors Temple and the Northwest Colonnade has often been referred to as decadent. Charlot finds that the style is not decadent in the sense of being deficient, either technically or stylistically. The work is beyond doubt of late date; nevertheless this later style has new features that were lacking in the earlier period. Our knowledge of Maya art would be incomplete indeed if it embraced only Copan and Palenque.

The last third of the book is on Murals from the Temple of the Warriors and adjacent Structures, by Mrs. Morris. She finds that three classes of mural design are evident in the group. One is the colossal serpent motive; a second is to be noted in the formal processional figures; and a third, in narrative and descriptive scenes. Toltec elements are found not only in the typical warrior, but also in the speech scroll, the formal planet and star symbols, the processional grouping of warriors accompanied by identifying glyphs, and the skull of the Death God with flint knife worn in the nose socket. Whether this means a borrowing from the valley of Mexico or by the valley of Mexico the author is unable to say.

The volume of 170 plates is a fitting supplement to the text and completes a work of which the authors have every reason to be proud. GEORGE GRANT MACCURDY.

United States Bureau of Mines; DR. SCOTT TURNER, Director.—Recent publications[1] of the Bureau of Mines are noted in the following list. (See earlier, vol. *22*, pp. 89, 90).

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[1] Copies of the publications of the Bureau of Mines may be obtained (at the prices indicated, by money order sent in advance) from the Superintendent of Documents, Government Printing Office, Washington, D. C. Orders should not be sent to the Bureau of Mines.

ANNUAL REPORT OF THE DIRECTOR FOR THE FISCAL YEAR ENDING JUNE 30, 1931. Pp. 61; 2 figs. and administration chart as of July 1.—Dr. Turner, in concluding his report, calls attention to the important achievements of the past year, and remarks that it has been one of the most successful years in the history of the Bureau. The special need at present is the new Experiment Station in Maryland, authorized last year.

BULLETINS.—No. 335. Quicksilver; by C. N. SCHUETTE. Pp. 168; 56 figs. (45 cents.)

No. 336. Agglutinating, coking, and by-products of coals from Pierce County, Wash.; by S. M. MARSHALL and B. M. BIRD. Pp. 31; 13 figs. (10 cents.).

No. 337. Jiggling, classification, tabling, and flotation tests of coals presenting difficult washing problems with particular reference to those from Pierce County, Washington; by B. M. BIRD and S. M. MARSHALL. Pp. vi, 132; 95 figs. (35 cents).

No. 338. Quarry accidents in the United States during the calendar year 1929; by W. W. ADAMS. Pp. 104 (20 cents).

No. 339. Petroleum refinery statistics, 1929; by G. R. HOPKINS. Pp. 125; 18 figs. (30 cents).

No. 340. Relationship between oxidizability and composition of coal; by WILFRID FRANCIS and H. M. MORRIS. Pp. 44; 5 figs. (10 cents).

No. 341. Coal-Mine fatalities in the United States, 1929; by W. W. ADAMS. Pp. 120; 78 tables (20 cents).

No. 342. Metal-Mine accidents in the United States, 1929; by W. W. ADAMS. Pp. 99; 1 fig., 69 tables (20 cents).

No 343. Permissible coal-handling equipment approved from January, 1926, to December, 1930, inclusive; by L. C. ILSLEY, E. J. GLEIM, and H. B. BRUNOT. Pp. 91; 29 figs. (35 cents).

No. 344. Methods and apparatus used in determining the gas, coke, and by-product-making properties of American coals; by A. C. FIELDNER, J. D. DAVIS, R. THIESSEN, E. B. KESTER, and W. A. SELVIG. Pp. v, 107; 53 figs. (40 cents).

No. 345. Concrete stoppings in coal mines for resisting explosions: Detailed tests of typical stoppings and strength of coal as a buttress; by GEORGE S. RICE, H. P. GREENWALD, H. C. HOWARTH, and S. AVINS. Pp. 63; 41 figs. (25 cents).

No. 347. Gases that occur in metal mines; by D. HARRINGTON and E. R. DENNY. Pp. 21 (5 cents).

MONOGRAPH. No. 4. Warning agents for fuel gases. Report to the American Gas Association; by A. C. FIELDNER, R. R. SAYERS, W. P. YANT, S. H. KATZ, J. B. SHOHAN, and R. D. LEITCH. Pp. 177; 31 figs. This volume gives the results of co-operative work of the Bureau of Mines and the Gas Association. New York, 1931. (Obtainable free from the Gas Association, 420 Lexington Ave.)

TECHNICAL PAPERS. Nos. 498, 499, 500, 501, 502, 503, 504, 505, 507, 508, 509, 513.

MINERAL RESOURCES of the United States, 1928; by FRANK J. KATZ, chief engineer, Division of Mineral Statistics. Part I, Metals. Pp. 910 ($1.50). Part II, Nonmetals. Pp. 801; 63 figs. ($1.25). Also many separate chapters for 1929 have been distributed.

SUMMARY OF THE MINERAL RESOURCES FOR 1930. Introduction by O. E. KIESSLING. Statistics assembled under the supervision of MARTHA B. CLARK. Pp. A 120, November 9, 1931 (20 cents).

LIST OF PUBLICATIONS, 1910-1931; with subject and author Index. Pp. 239.

Publications of the British Museum of Natural History.—The Trustees of the British Museum of Natural History have recently issued the following Guides to the wonderful collections under their charge. These include the following:

GENERAL GUIDE TO THE EXHIBITION GALLERIES (price one shilling).—This volume, of 249 pages and well illustrated, will be of much value to the visitor not already fully acquainted with the buildings and needing some instruction as to their contents. The frontispiece gives an impressive picture of the front of the building as seen from the southeast. This was first opened in April 1881; some important additions have been made since that date.

SPECIAL GUIDE, No. 8.—Guide to an Exhibition illustrating the early History of Palaeontology. Pp. 68; 4 pls. and 19 figs. (price nine pence). The exhibit prepared by Mr. W. N. Edwards, contains the books, manuscripts and specimens illustrating the historical study of fossils. The gradual transitions from the fanciful view of the organic remains in very early times to the rational understanding of to-day is well shown.

SPECIAL GUIDE, No. 9.—A short History of the Collections. Pp. 62 (price six pence). The growth of the collections from 1881-83 to the present is shown from the fact that the fossils have increased from 200,000 to 1,000,000; the recent vertebrates from 150,000 to 1,000,000; also the insects from one to eight millions.

Colorado Bureau of Mines, JOHN T. JOYCE, Commissioner of Mines. Annual Report for the year 1930. Pp. 64 with tables, Denver, 1931.—This report is of especial interest as showing that the mining industry of the State is still important, although no longer so strikingly prominent as in earlier years. Thus in 1930 the values of some of the products were as follows: $6,200,000 gold and silver; $20,500,000 coal; $3,400,000 zinc; $2,500,000 molybdenum; $2,300,000 lead. The total production of Colorado since 1859 has reached the large sum of $2,471,000,000.

Year Book of the Public Museum of the City of Milwaukee. Volume IX, pp. 270; figs. 1-191, 1929. Dr. S. A. BARRETT, Editor, and IRA EDWARDS, Assistant Editor.—This volume mentions briefly the development of the material received from the

Cudahy-Massee-Milwaukee Museum Expedition in Africa, 1928-29 (see this Journal, vol. *20*, p. 78, 1930). Considerable additions to the Museum building will be required before this large and very valuable collection can be adequately placed on exhibition.

Of the COLLECTING EXPEDITIONS in 1929 (pp. 7-167), the following deserve special mention: Archeological field work in Wisconsin by W. C. MCKERN; new and rare plants from the Southwest by A. M. FULLER; Collecting along the Yellowstone Trail by T. E. B. POPE; A Montana Miscellany by R. S. CORWIN; Historic Sites in New York State by W. D. KLINE. All of these are well illustrated by excellent plates.

Special notes follow (pp. 168-270), these describe the progress of the Museum's Group Building by S. A. BARRETT; Cave Men of Europe and Prehistoric Monuments of Brittany by GEO. A. WEST; also other matters of interest. The MUSEUM BULLETINS recently issued include Nos. 2 and 3 of Vol. 10; No. 2 by W. C. MCKERN on "A Wisconsin Variant of the Hopewell Culture." Pp. 185-328; pls. 31-60; figs. 13-26, maps 3-4. No. 3 by A. K. FISHER, H. W. KUHM and G. C. ADAMI on "The Dental Pathology of the Prehistoric Indians of Wisconsin." Pp. 329-374; pls. 61-70, figs. 27-29.

FIELD GUIDE, No. 1, of the Botanical Series, by HURON H. SMITH, June, 1931 (price 40 cents), gives brief descriptions of the "Mushrooms of the Milwaukee Region," with 182 illustrations of the species; also a tabular view of the genera.

PUBLICATIONS RECENTLY RECEIVED.

Stream Sculpture on the Atlantic Slope. A Study in the Evolution of Appalachian Rivers; by Douglas Johnson. New York, 1931 (Columbia University Press, $3.25).

The Theory of Spherical & Ellipsoidal Harmonics; by E. W. Hobson. New York, 1931 (Macmillan Co., $11.50).

Experimental Plant Physiology; by George James Peirce. New York, 1931 (Henry Holt and Co., $1.50).

A Textbook of Vertebrate Embryology. Revised Edition; by Robert S. McEwen. New York, 1931 (Henry Holt and Co., $4.75).

Dalradian Geology. The Dalradian Rocks of Scotland and Their Equivalents in Other Countries; by J. W. Gregory. London, 1931 (Methuen & Co., 12/6 net).

Matériaux pour l'Étude Des Calamités publies par les soins de la Société de Geographie de Genève. No. 26. No. II, Année 1931. Geneva.

Queen of the Sciences; by E. T. Bell. Baltimore, 1931 (The Williams & Wilkins Co., $1.00).

Report of the Secretary of the Smithsonian Institution 1931. Smithsonian Institution, Washington, D. C.

Annual Report of the Board of Regents of the Smithsonian Institution showing the Operations, Expenditures, and Condition of the Institution for the year ending June 30, 1930. Washington, D. C., 1931 (for sale by the Superintendent of Documents, $2.00 cloth).

The Geology of the Whitehaven and Workington District; by T. Eastwood, E. E. L. Dixon, S. E. Hollingworth, and Bernard Smith. (H. M.

Stationery Office, Adastral House, Kingsway) London W. C. 2, price 6/- postage extra.—Sheet 28. Whitehaven. Geological Survey of England and Wales.

The Use of the Self; by F. Matthias Alexander, with an Introduction by Professor John Dewey. New York, 1932 (E. P. Dutton Co., $2.00).

Report of the Librarian of Congress for the fiscal year ending June 30, 1931. Library of Congress. Washington, D. C., 1931 (United States Government Printing Office).

Theoretical Physics; by W. Wilson. Vol. I. Mechanics and Heat Newton-Carnot. New York, 1932 (E. P. Dutton & Co., $6.00).

Field Museum of Natural History, Chicago. Field Museum News for December, 1931, and January, 1932.

General Biology Laboratory Manual; by Leonas L. Burlingame, Arthur C. Giese and Robert E. Hungate. New York, 1931 (Henry Holt and Co., $1.25).

The Paleontology of Kentucky. A Symposium; by W. R. Jillson. Series Six, Vol. 36. The Kentucky Geological Survey. Frankfort, 1931.

A Guide to the Spring Flowers of Minnesota; by Carl O. Rosendahl and Frederic K. Butters. Minneapolis, 1931 (The University of Minnesota Press, $1.00).

Department of Education. Division of Geology. Nashville, Tennessee, 1931. Bulletin 41. A Preliminary Report on the Foraminifera of Tennessee; by Joseph A. Cushman. Bulletin 42. Preliminary Report on the Artesian Water Supply of Memphis, Tenn.; by F. G. Wells.

OBITUARY.

Dr. Charles Sheldon Hastings, for many years professor of physics in the Sheffield Scientific School of Yale University, died on January 31 at the age of eighty-three years. A notice is deferred until a later number.

Dr. Reginald Heber Howe, the American naturalist, died on January 28 at the age of fifty-six years. His work in ornithology and botany was of especial importance.

Dr. Andrew Alexander Blair, formerly chief chemist of the U. S. Geological Survey, died on January 25 in his eighty-fourth year.

Dr. John Wesley Young, professor of mathematics at Dartmouth College from 1911, died suddenly on February 17 at the age of fifty-two years. He had taught earlier at Northwestern University, at Princeton, also the Universities of Illinois and Chicago.

Sir David Bruce, the well-known physician, who spent a long life in laboring with signal success for the conquest of disease, especially in Africa, died on November 27 at the age of seventy-six years.

Dr. Gustave Le Bon, the veteran French scientist, died recently at the age of ninety-two years. He early devoted himself to physics and chemistry, and later published several works on psychology. He also discussed the relation of matter and energy, expressing the opinion that the former is "only a stable form of energy." His speculations on this subject were presented in volumes published in 1905 and 1907.

EDWARD HOPKINS JENKINS
1850-1931

Throughout the State of Connecticut, and far beyond its boundaries, for nearly half a century the name of Edward Hopkins Jenkins has been closely associated with the applications of science to agriculture.

Born in Falmouth, Massachusetts, May 31, 1850, Jenkins came to New Haven in 1868, graduating from Yale College with the class of 1872. The three following years he spent in the Sheffield Scientific School as a graduate student in chemistry, an additional year, 1875-1876, being given to the study of chemistry at the University of Leipzig. He received the degree of Ph.D. from Yale in 1879.

While a student at New Haven he came under the influence of Samuel W. Johnson who aroused in him a life-long interest in scientific agriculture. Johnson, as is well known, was the leader in the movement for the creation of Agricultural Experiment Stations in this country and in 1877 the State Legislature established on a permanent basis the Connecticut Agricultural Experiment Station at New Haven. This was the first organization of the kind in America, and Johnson was appointed as director and Jenkins as chemist.

Jenkins was thus started on his life-work, serving as vice-director 1882-1900 and as director 1900-1923, when he retired from active service. It is interesting to note that Jenkins was thus a direct descendant, through Johnson and John Addison Porter, of John Pitkin Norton, who in 1846 was appointed the first professor of scientific agriculture at Yale and who by his teachings and writings prepared the way for the application of scientific methods to agriculture.

It would be difficult to overestimate the value of Jenkins' work on agriculture in New England and especially in Connecticut. He was possessed of qualities that rendered him broadly useful, in directing the scientific work of the Experiment Station, in managing the business affairs connected therewith, in instructing the farmers of the State in a true appreciation of the helpfulness of science to progressive agriculture, and in many forms of service to the community at large. Endowed with high mentality, he possessed likewise kindliness and common-sense, qualities which added to his engaging personality enabled him to find his way through, or around, many obstacles which would have been unsurmountable by others less gifted.

The friends of Edward Hopkins Jenkins—and their name is legion—will not soon forget "his genial warmth, his kindly simplicity, his capacity for friendship," for these were traits in his character that endeared him to all who knew him.

RUSSELL H. CHITTENDEN.

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AMERICAN JOURNAL OF SCIENCE

APRIL 1932

STRUCTURAL SURVEY OF THE GRANODIORITE SOUTH OF MARIPOSA, CALIFORNIA.

ERNST CLOOS.

ABSTRACT.

South of Mariposa, California, the granodiorite of the Sierra Nevada sends an offshoot to the west, which terminates the southeast end of the ore-bearing Mother Lode zone. The primary structures of this outlier are described. The granodiorite has advanced from the east obliquely to the west, resting on the older sedimentaries on the southwest side. A comparison between the structure of the Mother Lode zone and the terminating igneous mass suggests that the movements of the Mother Lode zone preceded the final consolidation of the granodiorite.

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GENERAL STATEMENT.
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THE METHOD OF STRUCTURAL SURVEY.
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    Contacts of the Mariposa Intrusion.
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    Internal Structure of the Mariposa Intrusion.
STRUCTURE ELEMENTS OF THE SOLID STAGE.
SUMMARY.
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GENERAL STATEMENT.

In 1930 and 1931, the writer was engaged in mapping the section of the Sierra Nevada batholith[1] between Mono Lake and the Mother Lode (Yosemite National Park). In connection with this work the western contact of the batholith had to be examined, and the area south of Mariposa called for especial attention because here the Mother Lode zone is terminated by a large offshoot of granodiorite—referred to as the "Mariposa intrusion" in this paper—which extends westward

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[1] The term batholith is used in this paper without implication as to the genesis of the intrusive; see summary below.

AM. JOUR. SC.—FIFTH SERIES, VOL. XXIII, No. 135, APRIL, 1932.

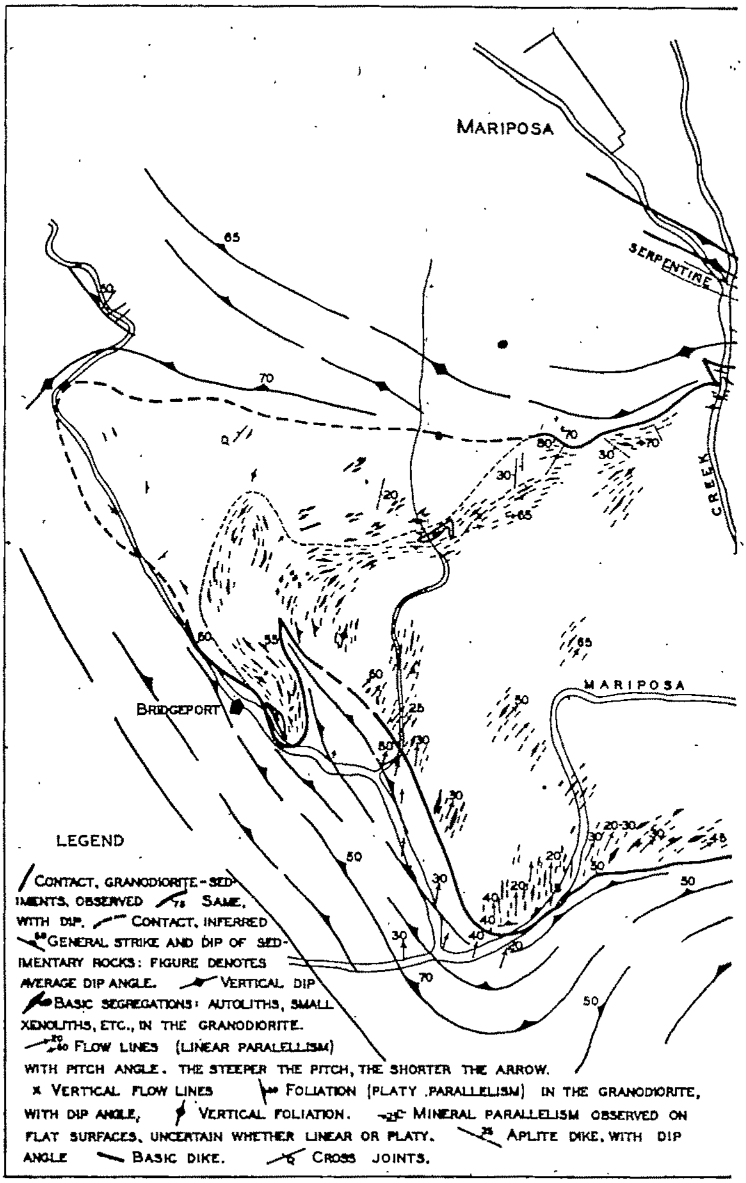
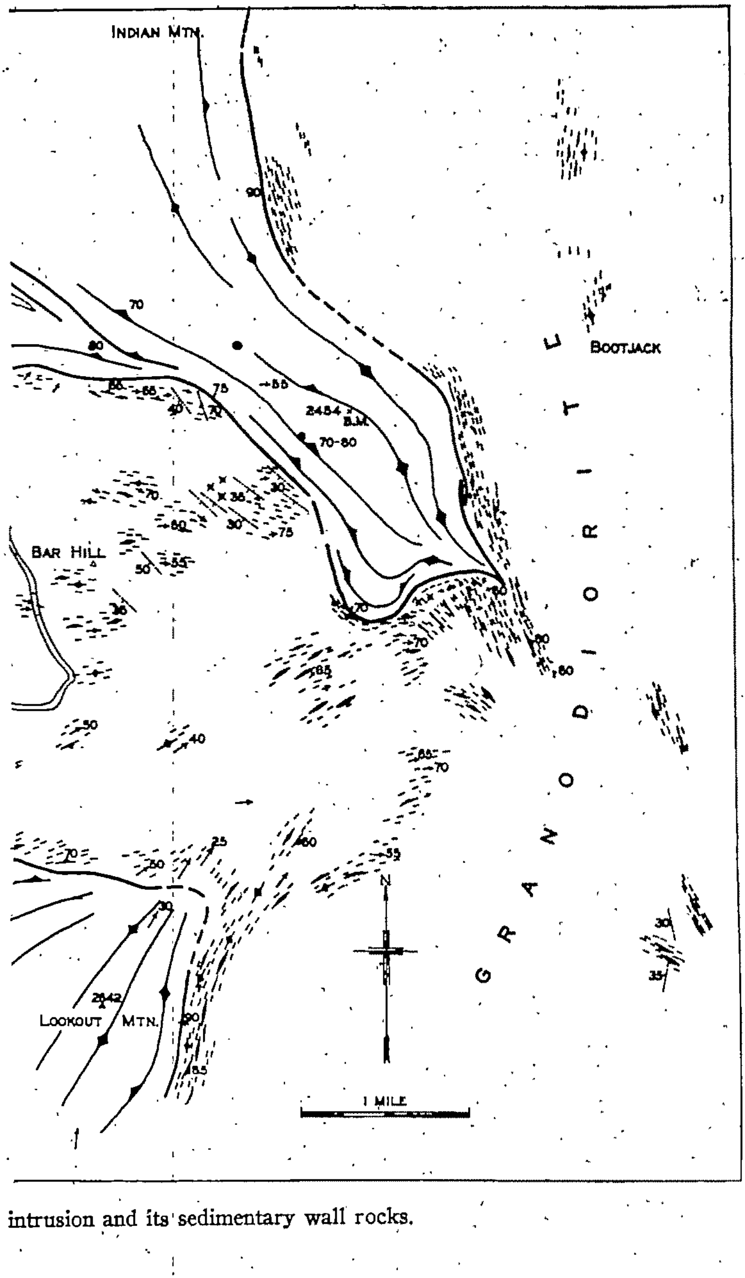

MARIPOSA
SERPENTINE
CREEK
MARIPOSA
BRIDGEPORT
LEGEND
CONTACT, GRANODIORITE-SEDIMENTS, OBSERVED
SAME, WITH DIP.
CONTACT, INFERRED
GENERAL STRIKE AND DIP OF SEDIMENTARY ROCKS: FIGURE DENOTES AVERAGE DIP ANGLE.
VERTICAL DIP
BASIC SEGREGATIONS: AUTOLITHS, SMALL XENOLITHS, ETC., IN THE GRANODIORITE.
FLOW LINES (LINEAR PARALELLISM) WITH PITCH ANGLE. THE STEEPER THE PITCH, THE SHORTER THE ARROW.
VERTICAL FLOW LINES
FOLIATION (PLATY PARALLELISM) IN THE GRANODIORITE, WITH DIP ANGLE.
VERTICAL FOLIATION.
MINERAL PARALLELISM OBSERVED ON FLAT SURFACES, UNCERTAIN WHETHER LINEAR OR PLATY.
APLITE DIKE, WITH DIP ANGLE
BASIC DIKE.
CROSS JOINTS.

Fig. 1. Structural map of the Mariposa



intrusion and its sedimentary wall rocks.

from the main mass of the Sierra Nevada batholith as far as Bridgeport, eight miles west of the Mother Lode zone. From the western contact near Bridgeport, one can travel eastward over well-exposed granitic rocks all the way to Owens Valley, across the Sierra Nevada, a distance of 80 miles. At a few localities only the uniformly light color of the granite exposures is interrupted by dark-colored metamorphosed sedimentary rocks which appear in a few cliffs.

As there is no geologic map of the Mariposa area in existence, the writer has mapped the contacts of the granodiorite as far as was necessary. The base of the map, Fig. 1, has been taken from the Mariposa sheet, 1: 125000.

A detailed structural survey was carried on for about four weeks in order to obtain information about: 1, the relation between the Mother Lode zone and the granodiorite; 2, the structural character of the west contact of the Sierra Nevada batholith. The results of this work are shown on the map, Fig. 1, in the block diagram, Fig. 2, and in Fig. 3.

Although the survey of the Mariposa area forms only a small part of the writer's work on the granodiorite of the Sierra Nevada, the description of this area is published separately, because it serves as a convenient "sample" to demonstrate the structural methods applied in this survey, and because of its bearing on the economic geology of the Mother Lode zone.

THE ROCKS.

The Sierra Nevada batholith is a complex mass, composed of a large number of granitic intrusions with slight petrographic differences, each of which has its own structural individuality[2]. (A detailed structure map of the whole area surveyed by the writer will be published later.) One of these masses, a granodiorite, comprising about 2% of the whole area investigated, forms the Mariposa intrusion, the subject matter of the present paper. To facilitate the discussion, the main intrusive of the Sierra Nevada, which lies to the east of the Mariposa intrusion, will be referred to as the "Main Mass," or The Batholith.

The rock of the Mariposa intrusion is described by Adolph Knopf on page 21 of the paper referred to:

[2] Knopf, A., The Mother Lode System of California. U. S. G. S. Prof. Paper 157, 1929. Calkins, F. C., in Matthes, F. E., Geologic History of the Yosemite Valley, U. S. G. S. Prof. Paper 160, 1930.

"Granodiorite."

"The Mother Lode belt, as has long been known, is terminated on the south by granodiorite that extends westward from the enormous masses of the high Sierra. The granodiorite appears at Mormon Bar, two miles south of Mariposa, and its contact continues westward approximately along the State Highway. It has exerted a strong contact metamorphism on the Mariposa slate the influence of which extends as much as a mile from the contact.

"The granodiorite yields immense outcrops of fresh rock, which present the forms characteristic of granite weathering in a warm arid climate, such as huge boulders resting insecurely on rock pedestals. The feldspars appear to be brilliantly fresh, but the hornblende weathers to yield a red iron pigment.

"The granodiorite is uniform in texture and composition, and it contains the basic clots, both the ellipsoidal and the angular, that are so common in it in the high Sierra. The granodiorite contains roughly 20 per cent of hornblende and biotite; andesine (Ab_{63} An_{37}) is the predominant light-colored mineral, orthoclase is subordinate, and quartz showing strain shadows is fairly abundant."

The Mariposa slate, Calaveras schist, and other wall rocks of the intrusive are also described by Knopf in the same paper.

A series of earlier basic intrusions (gabbro) was found in the northwest corner of the area, but as the exposures are poor and detailed petrographic study not a purpose of this investigation little attention was paid them. The rock boundaries appear as dotted lines on the map.

STRUCTURAL FEATURES.

A pronounced structural difference between the granodiorite of the main mass and the Mariposa intrusion was observed.

The granodiorite south of Mariposa shows a distinct flow structure, recognizable in the parallelism of mica and hornblende crystals, the parallel orientation of dark inclusions (basic clots or autoliths, and xenoliths, as described by Pabst[8]), and the orientation of swarms of inclusions, schlieren, and segregations. The parallelism is either linear, as produced by elements with one long and two short axes, e.g. hornblende needles and spindle-shaped inclusions, or platy, as produced by elements with two approximately equal and one appreciably shorter axis, e.g. mica crystals, and leaf-like or pancake-like inclusions. On the other hand, rock exposures without any distinct structure, or with equidimensional inclusions, are also common. In the field, the linear and platy structures are found either together or separately. The linear parallelism prevails in the western portion, but on approaching the eastern contact of the Mariposa intrusion, a platy parallelism of the minerals becomes more and more conspicuous.

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[8] Pabst, Adolf, Observations on Inclusions in the Granitic Rocks of the Sierra Nevada, Univ. of Cal. Dept. Geol. Publ. 17, No. 10, 325, 1930.

The granodiorite east of Mariposa shows an intense foliation, and linear parallelism of the minerals (flow lines) within the foliation planes. The dark inclusions are elongated and appear as thin sheets of dark material, in regular order and perfect parallelism. The rocks resemble gneisses in certain places. With greater distance from the contact, the intensity of the foliation and flow lines decreases, and gradations between strongly oriented parallelism and almost massive, structureless rocks have been found within four miles from the contact. Gradation from one type into the other has also been observed about five miles southeast of Mariposa, at the southeast end of the schist ridge which extends from Mariposa into the granodiorite. Along the southeastward extension of the Mother Lode zone, the contact between rocks of the Mariposa intrusion and the main mass is ill-defined and indistinct.

THE METHOD OF STRUCTURAL SURVEY.

The method of detailed structural mapping of granitic intrusions has been developed by Hans Cloos and his friends; a number of references are added at the end of the paper for the convenience of the reader. In its essence, the method consists in recording and measuring systematically the distribution, mutual relations, and orientation of all structural features or "elements," in so far as they resulted from the intrusion and incipient consolidation of the igneous rock.

In the granodiorite of the Mariposa intrusion, the following structural elements have been observed:

I. Elements of the viscous phase
    1. Linear structures
        a. parallelism of needle-shaped crystals (hornblende)
        b. parallelism of spindle-shaped inclusions (autoliths or xenoliths)
        c. schlieren of linear elongation
        d. chain-like swarms of inclusions of all kinds

2. Platy structures
    a. parallelism of crystals of discoid shape (mica)
    b. parallelism of inclusions of discoid shape
    c. platy schlieren

II. Elements of the closing viscous and incipient solid stage
    1. schlieren-like primary flexures
    2. primordial faults, filled with dike material

III. Elements of the solid stage
    1. early joints filled up with aplites, pegmatites, or basic dikes
    2. primary or early "barren" joints.

The orientation of these elements has been measured with a compass and clinometer and plotted on the map and in the block diagram. In order to check the individual observations, a large number of measurements had to be taken, and only the best exposures were relied upon, especially those where the rock could be examined from all directions. The map shows the most reliable measurements only. The areas of the exposures are slightly exaggerated.

STRUCTURE ELEMENTS OF THE STAGE OF VISCOSITY ALONG THE CONTACTS.

As the orientation of flow structures along border zones of igneous rocks is of especial significance, the contact zones of the granodiorite will be described first, to be followed by an outline of the flow structures in the interior of the Mariposa intrusion, and the structural elements resulting from the solid stage will be added under a separate heading.

Two types of contacts have to be considered in the area under discussion:

1. Contacts between the granodiorite on the one hand, and the wall rocks on the other (Calaveras and Mariposa formations, etc.).
2. The contact between the Mariposa intrusion and the main mass of the Sierra Nevada.

The first contact which separates rocks of widely different age, is sharp; the second contact represents only a gradation between two rock types of approximately the same age.

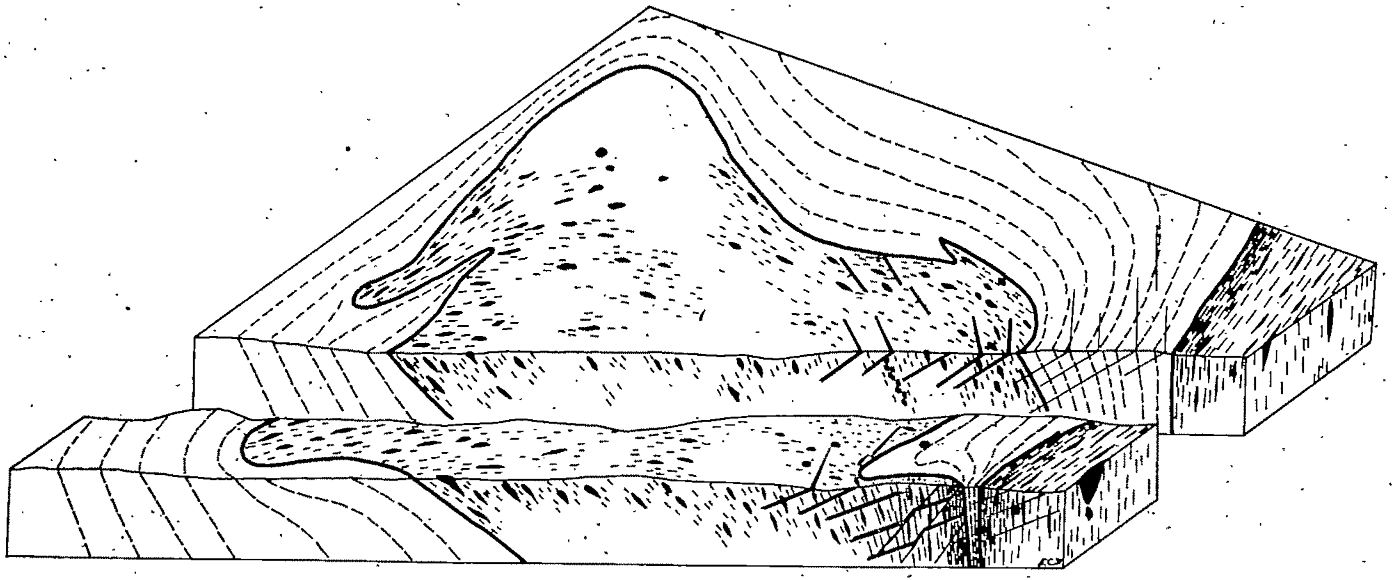

Fig. 2. Block diagram of the Mariposa intrusion. On the west side, the projected strike of the flow lines, as seen on horizontal surfaces, runs at right angles to the trend of the contact, while the pitch is parallel to the rock boundary, as shown on the vertical faces. Along the eastern contact, the marginal aplite dikes dip into the intrusive, and the shear zones in the lower block have the same orientation.

The map and the block diagram show the complicated form of the granodiorite body south of Mariposa. The main mass is situated east of a line which runs approximately north-south from Bear Creek Valley past Indian Mountain towards a line half a mile east of Lookout Mountain. The west contact of the batholith follows in a general way this line, dipping steeply, or standing vertical. In this contact zone a gap has been opened, two miles wide, which is located north of Lookout Mountain. The Mariposa intrusion has found its way through this gap, forming an individual, independent, and tongue-like body of granodiorite. The granodiorite crosses and terminates the Mother Lode zone in this gap.

Contact of the Mariposa Intrusion. Along its southern and western boundary, the contact dips ***under the granodiorite*** at gentle angles of from 15° to 50°. The northern contact dips steeply, being vertical in many places.

The northeast contact dips under a wedge-like salient of metamorphic rocks over a distance of several miles. This wedge, which is a mile and a half thick, is connected with the surrounding country rock on the northwest. This salient separates not only the Mariposa intrusion from the batholith on the east, but it also separates two plutonic areas of different structure; and finally it has to be regarded as the southeast end of the Mother Lode zone.

The contact of the Mariposa intrusion ***follows the structure of the surrounding country rock*** almost everywhere.

These conditions can be studied very well along the western and southwestern contact of the Mariposa intrusion. The bedding planes in the metamorphosed Mariposa formation form a syncline. Cleavage planes follow the same directions; a very intense linear parallelism coincides with the dip of the cleavage planes. The linear stretching is unusually intense, and is probably due to the granitic intrusion. The cleavage is "false cleavage,"[4] and follows the bedding planes in this particular area. Bedding, cleavage, and linear stretching dip (or pitch) ***under the granodiorite,*** and so do the axes of folds.

The normal regional trend of all rocks along the western slope of the Sierra Nevada is northwest-southeast. The rocks have been locally bent out of their normal direction, and the granodiorite which occupies the space between the distorted walls is inserted concordantly, intruding *between* the slates and schist layers rather than cutting across them.

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[4] Willis, B. and R., Geologic Structures, New York, McGraw-Hill Book Co., 1929. Behre, C. H., Slate in Northampton County, Pennsylvania, Penna. Geol. Surv., Bull. M9, 1927. Blackwelder, E., United States of America, Handbuch der regionalen Geologie, Bd. 8, Abt. 2 (Heft 11), Heidelberg, p. 177, 1912.

The same tendency towards concordant contact relations is observed along the western contact of the Sierra Nevada batholith. The granodiorite attempts to follow the easiest planes of advance, following the bedding or cleavage planes. As far as the writer is aware, concordant contacts are the rule.

Contact between the Main Mass and the Mariposa Intrusion. Although there is no distinct petrographic difference between the rocks of the two adjacent igneous bodies, their contact is represented by a *zone of intense movements* (shear zone of the closing stage of viscosity). The difference between the rocks on opposite sides of the contact zone lies in the intensity of the flow structures and their orientation, which differs up to 90°.

Approaching the contact, the granodiorite of the main mass manifests signs of pressure and primary movements by increasingly intense flow structures. This "inner contact zone" does not everywhere follow the granodiorite-schist boundary. It departs from this boundary about five miles southeast of Mariposa where the schist salient swerves to the west, and the pressure zone continues southeastward, clear across the granodiorite, separating the main mass from the Mariposa intrusion. This zone is the extension of the Mother Lode zone in general and can be traced into the granodiorite for miles. It is characterized by a rigorous orientation of all structural elements, such as cleavage, flow lines, inclusions, numerous dikes, flexures, and faults.

On approaching the zone from the Mariposa intrusion on the west, the flow structures which, so far, strike east-west, are seen to bend within a few hundred yards into the southeast-northwest direction of the pressure zone. The platy elements gain more and more importance; they are joined by cleavage planes; and flow lines, strike faults, cross faults, and flexures make their appearance. The zone itself has a width of about one half of a mile. The granodiorite of the east side is more strongly foliated than the rock on the west, and its parallelism follows the general northwest-southeast direction. Inclusions, cleavage, and linear parallelism dip steeply to the east, or stand vertical.

Flexures and faults in the pressure zone dip *westward,* at angles of about 50° and 70°. Filled with pegmatites and aplites, they represent movements during the close of the viscous stage. Cleavage planes are bent into their directions. The boundaries of the flexures and faults are not clean-cut, but schlieren-like, and show a distinct "drag" (Bailey Willis, 1929). Mica crystals are turned out of their normal position into parallelism with the faults and flexures. To judge from the drag along the faults and flexure zones, the eastern block has been uplifted with reference to the western block, the main mass against the Mariposa intrusive.

Steeply dipping cross faults and cross flexures are abundant, and the displacements along them indicate that the northeastern block has been moved northwestward with reference to the southwestern block. The movements along each one of these planes rarely exceed a few inches.

Internal Structure of the Mariposa Intrusion. The arrangement of the flow structures within the intrusive depends entirely on the form of the space which was available for the intrusion. The elements are oriented parallel to the contact planes. The planes of mineral parallelism follow the contacts in strike and dip, and the flow lines coincide with the dip of the contact planes. As far as the country rock is linearly stretched, the lines of flowage on either side of the contact are parallel.

As the northern contact of the Mariposa intrusive dips steeply, the platy foliation near the boundary plane dips also at a high angle, up to 90°.

The southern contact dips at a gentle angle *under the Mariposa intrusive,* and the linear parallelism pitches *into the granodiorite.*

The intensity of the flow structures in the granodiorite does *not* increase on approaching the contact. Apart from the flow lines, only an elusive platy parallelism is noted a few yards from the southern contact. All along the boundaries of the Mariposa intrusion, the contacts are sharp and could be marked with a pencil on exposures. The boundary cannot be predicted even two yards before it is seen, except by the *orientation* of the elements in general.

The structures of the rock enable us to reconstruct to a certain extent the shape of the body. Its roots are to be sought in the east, near its contact with the main mass. From here, a salient of the granodiorite has protruded into the country rock, using a gap which has been widened, if not opened, from the northeast towards the south.

It is very remarkable that the country rock at Lookout Mountain is virtually indistinguishable from the rocks which form the roof pendant southeast of Mariposa; it seems, indeed, as if one and the same belt of rocks has been split in two by the Mariposa intrusion. There is good evidence that we are dealing with metamorphosed Calaveras schists on both sides of the gap. In this case the Calaveras formation would have been bent considerably out of its normal direction by the granodiorite.

A horizontal section through the body half a mile below the present level would probably cut no more than one-half of the present area of granodiorite.

STRUCTURE ELEMENTS OF THE SOLID STAGE.

Joints and fissures in the granodiorite which have gaped so early that they have been filled up with silicic dike material, are most abundant in the northern and eastern portion of the Mariposa intrusion. Aplites and pegmatite dikes, dipping at angles of 30° to 50° southwest, are very numerous here. Ordinary "barren" joints, following the same direction, disregard the contacts, and can be seen in the adjacent wall rocks.

No such dikes and joints have been found in the southwestern half of the intrusive.

Dikes and joints of the same character as those just referred to have been described from various other places as feather joints (Hans Cloos[5]) and shear joints (Bailey Willis, l.c., figure 73, p. 143), which are caused by the relative displacement of two blocks. In the present area, these joints and dikes appear to have developed in response to the upward movement of the magma which is recorded by the steeply dipping flow structures along the northeastern contact of the Mariposa intrusion.

The restriction of these fissures to the northeast, and their

[5] Cloos, H., Bau und Bewegung der Gebirge in Nordamerika, Skandinavien und Mitteleuropa, Berlin, Gebr. Borntraeger, 1928. Cloos, Ernst, Tektonik des Granits von Gorkau, Kreis Nimptsch, in Schlesien. Abhandlungen der Preussischen Geol. Landesanstalt, Neue Folge, Heft 89, Berlin, 1922.

absence from the southwestern portion of the intrusive is therefore quite natural, because in the southwest the horizontal component of the magma movement equals, or predominates over, the vertical component.

SUMMARY.

A tongue-like body of granodiorite has been intruded from the Sierra Nevada batholith into the Calaveras and Mariposa formations, proceeding from east to west. Having pried open a gap in the wall rocks, the granodiorite has filled it, probably at the same time as the batholith found its present position.

The western contact of this offshoot, or "Mariposa intrusion," dips gently *under that body,* while the western contact of the main mass of granodiorite dips steeply eastward, or stands almost vertical.

Well-developed primary flow structures record the directions of flowage in the Mariposa intrusive. The body was protected against regional influences by a thin wedge of metamorphosed sediments, and has therefore attained a structural independence and individuality all of its own. The orientation of the flow structures depends entirely upon the form of the space which was available for the intruding mass.

As that wedge or roof pendant of metamorphic wall rocks forms the southeastern end of the Mother Lode zone, the Mariposa intrusion crosses the Mother Lode zone in the gap through which it is connected with the main mass.

A series of primary flexures and faults indicate block movements in the hardening magma, exactly in the continuation of the Mother Lode zone.

Well-defined structures have been developed in the same zone, consisting of cleavage planes, a strong foliation and parallelism of primary elements, and linear elongation. Flexures and faults are partly filled with dikes which thereby prove their early age. The relative upward movement continued for a short period after solidification of the Mariposa intrusion.

Primary feather joints or shear joints were also filled with dikes and so indicate the continuation of movements into the solid phase. Joints in the same direction in the wall rock show that the walls of the granodiorite were distended by the intruding mass, while the latter grew increasingly rigid.

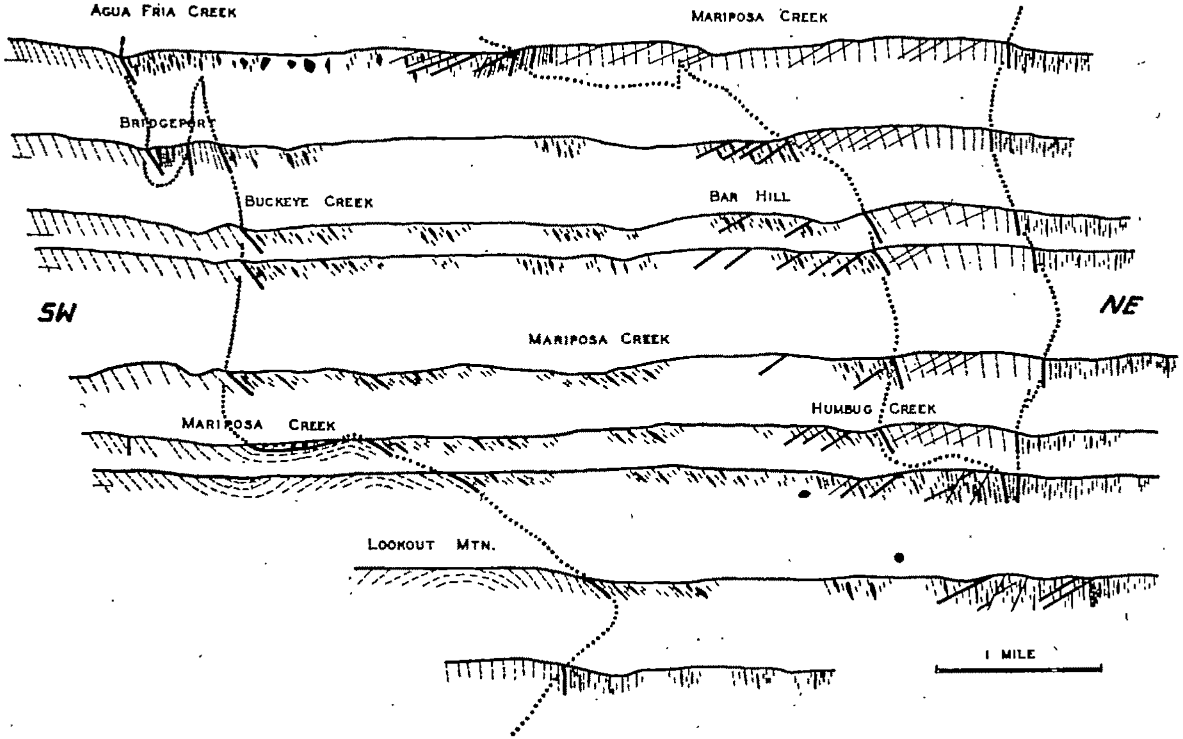

Fig. 3. Nine cross sections through the Mariposa intrusion in NE—SW. The symbols are the same as in Figures 1 and 2. In the schist salient southeast of Mariposa, the "marginal joints" are shown, which are joined by aplite dikes within the granodiorite.

Through-going faults, or upthrusts comparable to the main upthrusts in the Mother Lode zone farther northwest, have *not been found. This leads to the conclusion that the main movements along that zone have taken place before final fixation of the granodiorite,* and perhaps even while the latter was more or less plastic. On the other hand, traces of very early movements along this zone are obvious.

Thus it is believed that the Mother Lode zone has originated in the period between the beginning of the granodiorite intrusion and its final consolidation. The intrusion of the granite batholith seems to be responsible for it.

The western contact of the Sierra Nevada batholith in general, and south of Mariposa in particular, has *not been found to dip westward at any place.* The contact zone as well as the internal structures of the batholith stand either vertical, or *dip to the east, into the granodiorite.* These observations do not corroborate the conception of a growth and enlargement of the batholithic mass by replacement of older rocks in place. Many similar observations have been made between Mariposa and Sonora; they will be published later.

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PALEOZOIC DEFORMATIONS OF THE HUDSON VALLEY REGION, NEW YORK.

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The next International Congress (Washington, 1933) will offer an excursion up the Hudson Valley. Since not all the local information that is desired can be presented in the Guide Book, now under preparation, it is thought best to publish some of it at this time for future reference and to outline some of the general regional problems. The region between Rondout and Albany shared in the Taconian[1] deformation of late Ordovician time, and after peneplanation the deformed strata were covered by the sea late in Silurian and especially in earliest Devonian times (= Helderbergian); the marked unconformity to be described in this article resulted. The Silurian and Devonian formations also were deformed by folding and thrusting, probably during the Appalachian revolution. Several localities that furnish evidence for these two important deformations were visited during the spring months of 1931 by the authors, together with Professor Adolph Knopf, Dr. Eleanora B. Knopf, and Dr. Anna I. Jonas. Later in the summer Professor George H. Chadwick, who has mapped the Catskill Quadrangle and is intimately acquainted with the geology of the general region, kindly acted as guide to a number of important outcrops.

To understand fully the stratigraphy and historical geology of the Hudson Valley from Newburgh and Kingston north to Albany (Fig. 1), the student should keep in mind that the Ordovician formations here are of two facies, an eastern and a western; and that the eastern sequence now lies partially thrust over the formations of the western facies. Just where to the south the eastern sequence disappears is not yet determined; it is known to be present but much narrowed south of Newburgh, and probably it dies out in northwestern New Jersey. All of the Ordovician discussed in this paper is of the eastern sequence. Formations younger than the Ordovician occur almost entirely west of the Hudson River, but the northernmost outcrops are in Becraft Mountain, east of the river about 30 miles south of Albany.

The Catskill-Rondout folded area, which lies chiefly between the Hudson River on the east and the nearly horizontal strata of the Catskill Mountains on the west, Davis (1883, a) named the Little Mountains. This physiographic

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[1] The form Taconian is used in connection with late Ordovician movements and resulting features in this belt, to prevent confusion with the present *Taconic* Mountains.

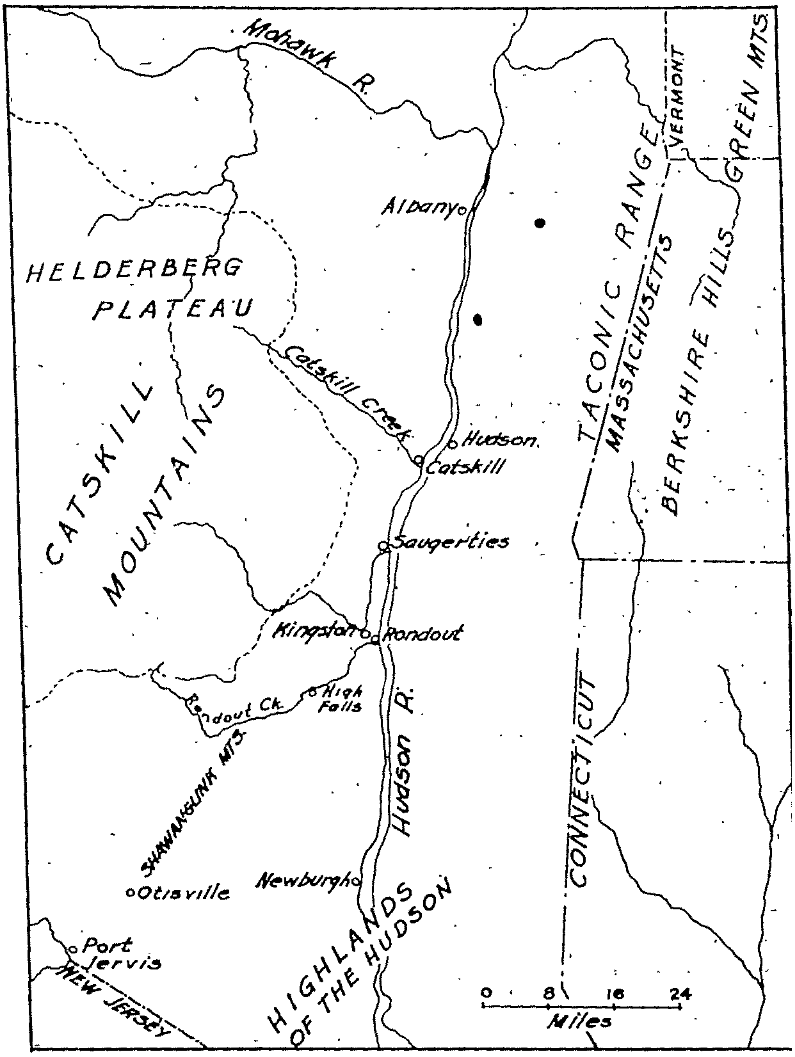

Fig. 1. Index map of the Hudson Valley between Albany and th Highlands, with adjacent areas to the east and west.

unit, which resembles the Appalachian Mountains in miniature ends south of Albany.

REGION ABOUT RONDOUT, ULSTER COUNTY.

In the hill known as the Vlightberg, which fronts the Hudson River to the east of Rondout (Fig. 1), the strata listed in the following table are exposed. Thicknesses reported by three geologists are given, and thicknesses of certain formations west of Albany are added.

		Van Ingen 1903	Davis 1883	Hartnagel 1903	West of Albany
Lower Devonian or Helderbergian	Oriskany. Lower congl. (6′-18′) and sandy ls. (20′-50′)	60	20–30		
	Port Ewen shaly ls. (syn. Kingston)	110–200	100–150		
	Becraft ls.	40	30–40		
	New Scotland shaly ls.	100+	60		100–120
	Coeymans ls.	50	30–40		50
Upper Silurian or Cayugan	Manlius. Ribbon ls., etc., (13′), Stromatopora beds (13′), and Manlius proper (= Tentaculite ls.) 16′	42	70	37.6	45–57
	Rondout waterlime or cement rock	20		24.4	6–12
	Cobleskill of authors	5–7	6–8		
	Salina cement ls. incl. basal Wilbur ls. (7′)				17
	Great time break; angular unconformity				
Middle Ordovician	"Hudson River" ss. and interbedded sandy shale, dipping NE. In places "Heavy bedded ss. of rather fine texture and considerable hardness, as in Huzzy's Hill [about 2 m. S. of Kingston] . . . and sometimes shaly and much contorted, as along the banks of the stream at Eddyville" (Davis, 1883, b, p. 389). Van Ingen-Clark (1903) give the thickness as 1000′+, and correlate it with the Normanskill, as does Ruedemann.				

All of the Silurian formations thicken rapidly to the southwest; they thin and vanish within a short distance to the east, and thin more gradually to the northeast.

Angular Unconformity.—The crustal deformation that has come to be known as the Taconian was described first at Rondout, in the publications of W. W. Mather (1838); and more especially of H. D. Rogers. The classical area of this deformation lies between Hudson (Becraft Mt.) in the north and Otisville, near the New Jersey line, a distance of about 85 miles. The clarity with which Rogers (1838, p. 37) saw and described the evidence of this disturbance is remarkable for its time, and no one has seriously disputed it in the area between the points noted above.

The entire Siluro-Devonian about Rondout is much folded and thrust-faulted, but clearly it is separated from the Ordovician by a strong angular unconformity. The contact is well shown in abandoned quarries on the southeast side of the Vlightberg, which is ½ mile long and ⅛ mile wide. In one quarry "the sandstone strikes N. 10° W. (true meridian) with an easterly dip of 60°; and the Wilbur limestone [of the overlying series] strikes N. 55° E.; dip 30° NW." (Van Ingen, 1903, p. 1210). In another excellent exposure the Ordovician sandstone strikes N. 30° W., dips 52° NE.; the Wilbur limestone, resting on the eroded edges of the sandstone, strikes N. 50° E., dips 80° NW. (Fig. 2).

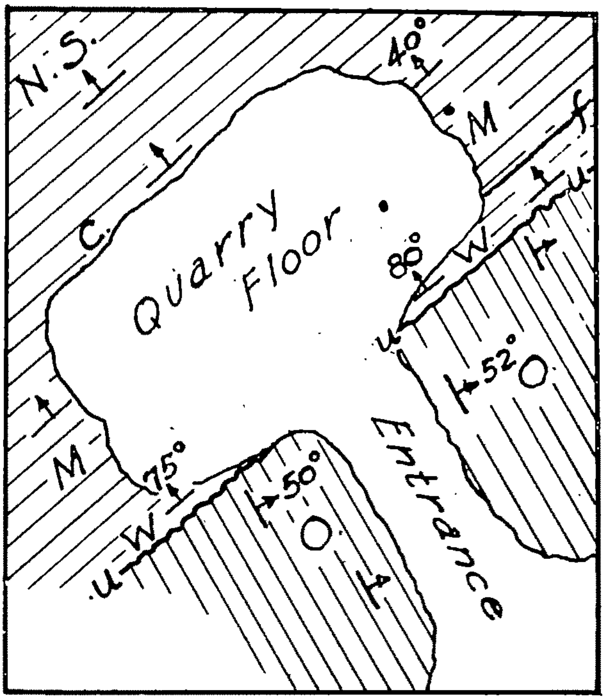

Fig. 2. Sketch-geologic map of old quarry on the east side of the Vlightberg, at Rondout. O = Ordovician, W = Wilbur limestone, M = Manlius limestone, C = Coeymans limestone, N. S. = New Scotland limestone, u-u = unconformable contact between the Ordovician and Silurian; f is a small bedding fault.

This marked unconformable contact is pictured by Rogers (1858, II, p. 785) and by Davis (1883, b, p. 382; 1883, a).

"It is noteworthy that the limestone [= Wilbur] begins immediately with its fully determined calcareous character; there is no band of transitional composition; no fragments of the sandstone are contained in it. . . . . The old worn surface was swept clean before the corals and crinoids began growing" upon the upturned Hudson River sandstone and shales (Davis, 1883, b, p. 393). Upper Silurian fossils are found directly above the contact.

The "Hudson River sandstones" (= Normanskill) and shales are highly tilted and locally much contorted. The series consists of either "graywackes, or quartz sandstones with argillaceous cement and with little lime content . . . when fresh, olive gray and, when weathered, dark gray, brown or blackish. . . . Some of the heavier layers of sandstone have their surfaces dotted with flattened pebbles of dark shale from ½ to 2 inches in diameter, which appear to have been soft mud when they were deposited there. . . . Cross bedding is common. . . . the thinly bedded sandstones with shale partings show ripple marks and sun cracks. Fossils are rare. . . . *Plectambonites sericea* and *Dalmanella testudinaria* [=?*D. rogata*]; and a few undetermined graptolites have been found in the shale on Kingston Point. . . . In all cases where the contact has been exposed [it is seen] to be sharply and distinctly unconformable to the overlying limestones." In the Vlightberg the local irregularities of erosion vary from 6 to 24 inches in height (Van Ingen and Clark, 1903, pp. 1181, 1209).

The principal structural features of the Siluro-Devonian in the Vlightberg "are a monocline and two anticlines, all of northeasterly trend, and a small overthrust block" (p. 1211). The "thrust is from the southeast . . . along an almost horizontal plane toward the northwest" (p. 1219).

In the North Hill, north of the Vlightberg, there is "a shallow synclinal structure with the beds at the eastern edge of the trough dipping steeply westward." The strike is generally about N. 20° E. Here occurs "the White lime quarry overthrust fault." The thrust plate has been thrown to the west at least 1,100 feet and forms a veneer to the top of the North Hill (pp. 1221, 1225).

Van Ingen and Clark conclude that these structures "can be assigned to the typical Appalachian orogenic movements at the close of the Paleozoic era" (1226, p. 7). Davis reached the same conclusion, saying that the folding was "presumably contemporaneous with the great Appalachian disturbance" (1883, b, p. 393); and others who have studied the Devonian structures of this region are of the same opinion. The Ordovician formations beneath had previously experienced the Taconian folding.

REGION SOUTHWEST OF RONDOUT.

As one goes southwest from Rondout and notes the stratigraphic succession, it is seen that not only formations of the late Silurian older than the Wilbur member of the Rondout series are introduced, but also a much older series of the same system; and that both series swell to great thicknesses. In this we see evidence of the entrance into the deeper part of the Appalachian geosyncline.

Taking up the older Silurian first, we begin with the equivalent of the Medina in the conspicuous Shawangunk white quartzite and conglomerate, none of which is present at Rondout. The most northerly outcrop of the Shawangunk occurs less than 2 miles south of Rondout or just to the west of New Salem, where it is between 15 feet and 20 feet thick and conformably underlies the Waterlime and the Oneida conglomerate. Ten miles southwest of Rondout, in the region of High Falls and Binnewater, Ulster County, the Shawangunk lies with angular unconformity on the Hudson River series of the Ordovician. Here the Shawangunk has a thickness ranging up to 90 feet and thence it thickens rapidly to the southwest. Schuchert (1916, p. 536) says: "In about 85 miles the Shawangunk has increased from 10 to 1,565 feet, or at the rate of more than 18 feet per mile. In this greater thickness are included some strata of the next younger formation, the Clinton."

Much information about the Shawangunk and associated formations was obtained during the construction of the Catskill aqueduct across the Rondout Valley, and the following is taken from Brown (1914). At shaft No. 8 south of High Falls, the Shawangunk is faulted off at the top and therefore shows only the lower 30 feet of quartzite, beneath which the contact with the Hudson River series "was distinctly shown and it was a distinct erosional unconformity." Farther west another normal contact was observed and here the basal bed of the Shawangunk is a bright olive-green shale lying unconformably on the Hudson River series. In shaft No. 6 "the Hudson River beds were dipping at a considerable angle and the lower part of the Shawangunk beds [not at all so deformed] consisted of 2 to 3 feet of light olive-green shale" (pp. 471-2). In this area, then, there is evidence of an angular unconformity between the Hudson River series and the Shawangunk or Medinan of the Silurian. The unconformity at this same horizon is recognized at Otisville, New York, and in southeastern Pennsylvania (Stose, 1930).

In addition to the Shawangunk the red Salina series is missing at Rondout. Therefore two thick sets of marine formations come in between the Ordovician Hudson River series and the Siluro-Devonian limestones as we go southwest from Rondout. Directly beneath the limestones is the Salina series of the late Silurian, which finally reaches a thickness of 2,500 feet; and under the Salina, separated from it by a depositional break, is an early Silurian series, the Medina (Shawangunk)-Clinton, which swells out to 1,565 feet. The duration of this break in the Hudson Valley is represented by the Lockport-Guelph dolomites of western New York and Ontario.

AREA BETWEEN RONDOUT AND CATSKILL.[2]

Saugerties Area.—About 12 miles north of Rondout there is a good Helderbergian exposure, near the main highway to Albany about one mile northeast of the railway station at Saugerties. Here there is a flat thrust fault, with the Port Ewen, Becraft, and New Scotland limestones pushed over the same formations to the west (Chadwick, 1910). The Hudson River series is not exposed at this locality.

Lehigh Quarries South of Westcamp.—About a mile south of Westcamp and west of the highway are the extensive Lehigh limestone quarries in strata of Upper Silurian and Lower Devonian age (Manlius, Coeymans, New Scotland, Becraft, and Alsen formations). These limestones are much folded, especially the New Scotland shaly limestone, and there are fine examples of local overthrusting from the east toward the west. At the north end of the quarries the Alsen and Becraft limestones dip gently beneath a flat thrust, and strata in the overthrust mass, ranging from New Scotland to Alsen, are nearly vertical, with strong drag to the east along the thrust surface (Fig. 3). Part of the same thrust is exposed in another cut on the east side of the hill.

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[2] All of the features mentioned in this section have been studied in detail by Chadwick and are described in his manuscript to be published by the New York State Museum.

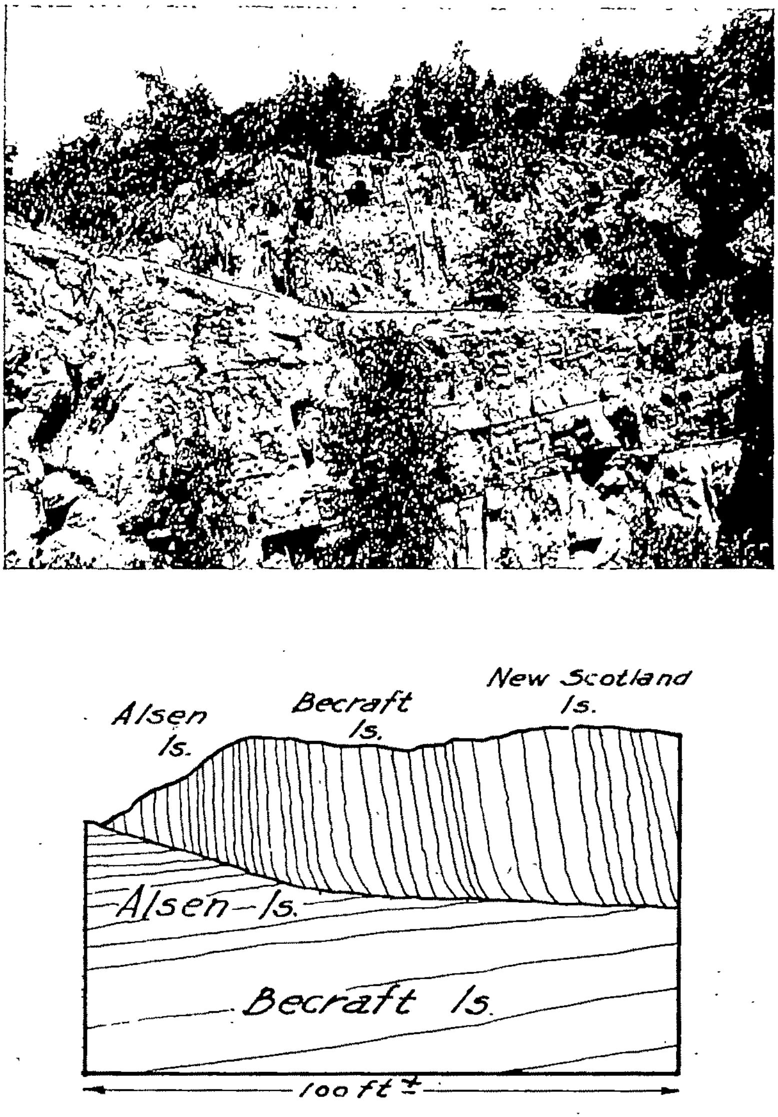

Fig. 3. A, thrust in Devonian limestones, north end of Lehigh quarries at Alsen; B, sketch to explain the structural relations shown in the view from *E* to *W* (minor complications of the structure beneath the thrust are omitted in the sketch).

A long tunnel through the ridge connects these extensive quarries with another in a valley about a mile to the northwest. At the west end of the tunnel, on the north side of the portal, the Upper Silurian limestone rests with strong angular unconformity on the Ordovician sandstones and shales. There is a better exposure of this unconformity in the quarry, which is reached by following the track northward from the tunnel. Near the entrance to the quarry the Ordovician beds strike N. 5° E. and dip 30° to 55° eastward; the overlying Silurian strata strike N. 35° E. and dip 20° northwest (Fig. 4). The bottom surface of the lowest Silurian bed, exposed by undercutting in the quarrying operations, has numerous original irregularities, including a network of ropy projections which probably are casts of worm trails. It is evident, therefore, that there has been no slipping along the contact since the Silurian strata were deposited. Graptolites in the Ordovician at this locality are identified by Ruedemann as typical Normanskill forms; we saw here *Climacograptus bicornis peltifer.*

Westcamp, Ulster County.—About a mile north of the Alsen cement plant (eight miles south of Catskill) there is a good exposure of the angular unconformity on the west side of the highway. The Ordovician strata strike generally north-south and dip eastward at a high angle; the overlying Silurian limestone is nearly horizontal. Devonian limestones up to and including the Becraft are exposed in the cliff above.

Catskill, Green County.—In the Broom Street quarry at Catskill, Chadwick collected and Clarke and Ruedemann (1912) have described the following fauna: Of graptolites, *Dicellograptus gurleyi* Lapw., *Climacograptus bicornis* Hall and var. *peltifer* Lapw., and *Cryptograptus tricornis* (Carr.), all European forms. Of small eurypterids there are: *Eurypterus chadwicki, Eusarcus linguatus, E. nasutus, Dolichopterus breviceps, Stylonurus modestus,* and *Pterygotus normanskillensis.* These fossils occur in thin black shale zones between the layers of greywacke ("blue-stone") in beds from 3 to 30 feet thick. "This graptolite association is one of undoubted Normanskill age" (p. 412). The most abundant fossil is a seaweed known as *Rhombodictyon,* originally described as a sponge. This is a typical Normanskill fauna.

The small gorge of Catskill Creek (Austin Glen), in which lie the ruins of Austin's mill, is about a mile west of the town of Catskill, the area around which centers Irving's legend of Rip Van Winkle. The most detailed published account of the

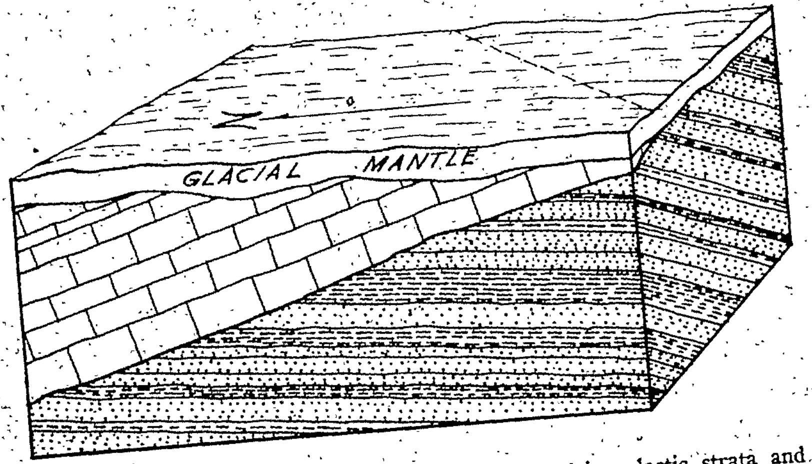

Fig. 4. A, angular unconformity between Ordovician clastic strata and Upper Silurian limestone. Western Lehigh quarry, west of Alsen. A pen line marks the position of the contact. View looking northeast. B, block diagram to show more clearly the relations in (A). Broken line on the surface represents the strike of the Silurian and approximate position of the contact beneath the mantle.

geology, with a map of the formations (area about 10 miles long), is that of Davis (1883, a). He gives the following stratigraphic sequence for the Catskill area:

		Catskill	Becraft
Lower Devonian or Helder-bergian	Becraft limestone, incl. Port Ewen limestone. Measured thickness (at Leeds) may be erroneous because of faulting.	?120	70
	New Scotland shaly limestone	100–	75
	Coeymans ls. (upper, 70′; Ribbon, 1-2′; coarse, 10′)	80	45
Upper Silurian or Cayugan	Manlius ls. (lower Ribbon, 12′; Stromatopora, 1-2′; Tentaculite ls. and Waterlime shaly limestone. (Less thick at Austin's mill than at Leeds)	70	55
	?Wilbur sandy limestone, has no fossils	5–10	0
	Great time break, but with no visible unconformity.		
Middle Ordovician	"Hudson River" greywackes and sandy shale of the same age as at Rondout, up to 1000′ or more thick (= Normanskill).		

Ordovician of Austin Glen.—Davis (1883, a, p. 314) says that the Hudson River sandstones "contain flakes of many-colored clay with the fine sand, implying an erosion near the place of deposition, and some layers have an uneven surface like a mudflow. Irregular ripple-marks are common, and in good exposures they may be seen over large surfaces; but we found no cross-bedding or coarse sandy layers. No fossils were seen; their absence cannot be ascribed to metamorphism, either mechanical or chemical, for many of the strata seem very little altered in spite of the general disturbance. . . Sharp folds, slickensides, and small faults are very common. . . A point of good, continuous, and just now [1882] of fresh exposure, is in the railroad cut on the bank of the Catskill just below Austin's mill [the track is now abandoned]; a fine dome-like fold is seen by the stream, and farther on [west] broadly curved surfaces of rippled shales alternating with firm sandstones dip conformably under the limestones [Davis illustrates the attitude of the strata in his Fig. 3]. Unconformity might well be expected; the Medina, Clinton, Niagara, and Salina series, about one thousand feet thick in Western New York and over six thousand in Central Pennsylvania, are all absent here."

To the description given by Davis the authors add the following observations: The Ordovician strata here have a general strike N. 50° E. Sandstone layers from a few inches to several feet in thickness alternate with thin layers of fissile shale. Much of the sandstone is typical greywacke, the fine grains consisting of quartz and plagioclase feldspar, with a generous admixture of the clay or shale flakes mentioned by Davis and scattered pieces of black chert. Although most of the shale flakes are small, some are several inches across. Since these pieces resemble the shale with which the sandstone is interbedded, they may have been torn up from the bottom by wave or current action and therefore do not necessarily imply subaerial erosion near the place of deposition, as Davis suggests. However, the larger grains of feldspar, quartz, and chert are angular or subrounded and hence indicate land at no great distance. These materials may have been supplied by the Rensselaer grit now exposed on the highlands east of the Hudson Valley, or by older metamorphic and igneous rocks somewhat farther east.

The markings "like a mud flow" are sandstone casts of irregular ripple marks that were made on sandy shale layers below. At least five such layers can be seen in the vicinity of the old mill, and in every case the markings are at the base of sandstone beds that rest on shale. One of the sandstone layers near the site of the old mill is distinctly cross-bedded; the sweeping laminae truncated by one bedding plane and converging tangentially in the opposite direction furnish a valuable clue to the structure, since the strata dip at a high angle.

Below Austin's mill and the "fine dome-like fold," Doctor Jonas found slabs of fine-grained greywacke covered with well-preserved specimens of a single species of *Climacograptus* that Doctor Ruedemann has identified as *C. bicornis peltifer.*

Structural Relation between Silurian and Ordovician.—On the roadway leading down to the old mill the basal Silurian beds are exposed near outcrops of the Hudson River strata, but not actually in contact with them. Strata in the two systems have the same general dip on the northwest limb of an anticline; but in the roadway the Ordovician beds are vertical or slightly overturned, and there is a suggestion of local angular unconformity with the overlying Silurian, although the evidence is not conclusive. The lowest Silurian beds, which are 5 to 10 feet thick, consist of rusty-weathering, unfossiliferous, sandy limestone; they probably are the equivalent of the Wilbur limestone. In a pasture lot above the cliffs east of the old road, good outcrops of the basal Silurian and the Ordovician are very close together, although the actual contact is concealed. Both series of strata dip steeply to the northwest, apparently without angular discordance.

Davis (1883, a, p. 322) says: "West of Catskill, I am persuaded that no [angular] unconformity exists. . . The entire series is conformable in this district, and is folded together," i.e., the Hudson River and Helderberg series were folded together, presumably during the Appalachian revolution. We do not find, however, that the field evidence warrants this positive conclusion. It is true that the Ordovician at this locality was considerably disturbed with the later formations and therefore could not have been closely folded in pre-Silurian time; but the outcrops that indicate general conformity are in one limb of a fold, and even so there is some suggestion of local angular discordance.

Chadwick reports (1913) that since the old mill dam was removed the Silurian-Ordovician contact is well exposed in the creek bed above the mill site. He states that there is a distinct angular unconformity at this locality, although the discordance is less pronounced than that at Rondout and Westcamp. Unfortunately the creek has been in flood and the critical outcrops concealed each time the present writers have visited the glen; but the description given by Chadwick is convincing. It is not surprising to find evidence of more moderate discordance as one goes west from the Hudson River, since it is well known that the Taconian folding dies out rather rapidly westward.

BECRAFT MOUNTAIN NEAR HUDSON.

A little over a mile southeast of the city of Hudson, Columbia County, and about 2 miles east of the river is Becraft Mountain with Siluro-Devonian limestones lying unconformably on the highly deformed Hudson River (= Normanskill?) series of the eastern sequence. The ovate outlier, about 2½ miles long from north to south and about 1½ miles wide, is replete with quarries and cement mills. The stratigraphic sequence here, as given by Clarke (1900) and by Grabau (1903), is as follows:

Middle Devonian	Onondaga ls.	225 feet	20–25 feet
	Schoharie grit		200 "
Lower Devonian or Helderbergian	Esopus grit	275-300 feet	100 "
	Oriskany quartzite		1–2 "
	Port Ewen ls.		25 "
	Becraft ls.		40–45 "
	New Scotland shaly ls.		70–75 "
	Coeymans ls.		42–45 "
	Manlius or uppermost Silurian		55 "
	Great time break and angular unconformity.		
Middle Ordovician	"Hudson River" folded and crumpled shales of the Normanskill (?) series (= late Chazy).		

The Siluro-Devonian series of Becraft Mountain occurs as a more or less modified and much faulted syncline, with the sharpest folding and faulting in the southeast. The general strike of the folds is slightly east of north with the syncline pitching gently to the south. There are many overturned folds and even overthrust masses, but all such features are of limited extent. As Davis says (1883), the entire deformation is a "small imitation of Appalachian structure." At the northern end of the outlier the limestones are essentially horizontal; but on the southeastern side "they are turned up abruptly so as to stand on end with a strike varying from west-east to N. 70° E." (p. 383). Evidently the Becraft outlier is the basal remnant of a major syncline that originally contained about 1 mile thickness of Siluro-Devonian strata.

The exact age of the underlying Hudson River shales remains undetermined, since no fossils have ever been found in the Ordovician about the mountain itself. On the basis of graptolites collected nearby, however, the time of deposition is probably Middle Ordovician, and more specifically Normanskill, but the possibility of Snake Hill time is not excluded. To the west in Mount Moreno both Normanskill (Middle) and Deepkill (high Lower Ordovician) graptolites occur.

The Ordovician series is well exposed on the southwestern side of Becraft Mountain back of the home of Fred. G. Lambert, where it is much folded and crumpled; the Manlius above lies in broad open folds. But the best place to see the unweathered shales is farther north, in the quarry beside the tramway of the Jonesburgh cement mill, where the contact with the overlying Manlius limestone is well exposed. The shale here is an olive-green fissile rock. Grabau (1903) and Davis (1883) give the strike in the Jonesburgh quarries as N. 50-55° E., and the dip as 25-35° SE.; but with better exposures one now sees that the shale is locally very much crumpled, with every possible angle of dip up to the vertical, although no cleavage has been developed. Above the great angular unconformity the Manlius lies with a dip of 10-15° SE., and a strike of N. 35° E. Small valley-like depressions at the top of the crumpled Ordovician are filled with slightly conglomeratic beds at the base of the Manlius (Fig. 5).

Just north of the southern end of Becraft Mountain on the main highway to New York, near Smith's Inn, there are outcrops of a very different Ordovician formation consisting of shale, thin-bedded black chert, grits, and siliceous limestones.

These Davis (1883) also noted, although the exposures at that time were weathered and obscure. Recent work in widening the road has laid bare the fresh rock, but only a small thickness of the Ordovician is visible and its relation to younger formations is not shown. At the end of the hill, where the highway turns eastward, a prominent cliff gives an excellent display of disturbed Devonian strata (Fig. 6). The lower part of the cliff is made of sparsely fossiliferous New Scotland beds which are nearly horizontal; but they are offset by numerous small thrust faults, and there are slickensides on nearly every bedding plane. At the top of the cliff is the Coeymans limestone, separated from the younger New Scotland beds beneath by a thrust plane that dips gently to the east. In the cliff face the position of the thrust contact is marked by a whitish band of secondary calcite. Near the west end of the cliff the Coeymans strata are rolled forward and turned under along the thrust; farther east they are less deformed.

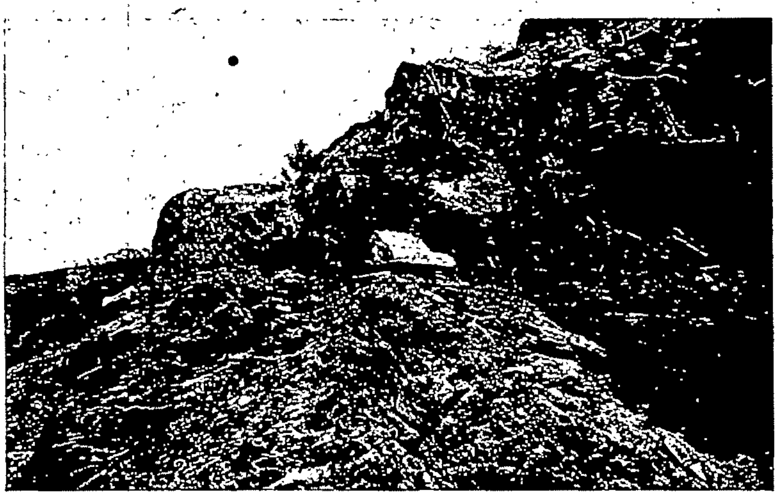

Fig. 5. Unconformity at Jonesburgh quarries, west side of Becraft Mountain. Note the valley-like depressions in the crumpled Ordovician shale, filled with local Silurian beds. View looking east.

Unconformity.—Davis (1883) says that Mather, Rogers, and Dana described the contact of Becraft Mountain as unconformable, "while Emmons showed the contact of the upper and lower rocks conformable, and Hall was disposed to take this view" (p. 381). Davis concluded that "the weight of evidence here seems to be in favor of nonconformity" (p. 385). Grabau (1903) says: "This contact is everywhere a markedly unconformable one, the Hudson River strata being much folded and truncated by erosion before the deposition of the Manlius limestone" (p. 1037). The excellent exposures now available demonstrate beyond question the existence of a pronounced angular unconformity; the fine contact exposed in the Jonesburgh quarry is in itself convincing proof of severe folding and extensive erosion before deposition of the Manlius formation. Stratigraphic considerations emphasize the importance of the unconformity; the Ordovician seas left the rising Taconian belt toward the close of Trenton time, and therefore the area was undergoing erosion throughout all of Upper Ordovician and about nine-tenths of Silurian time.

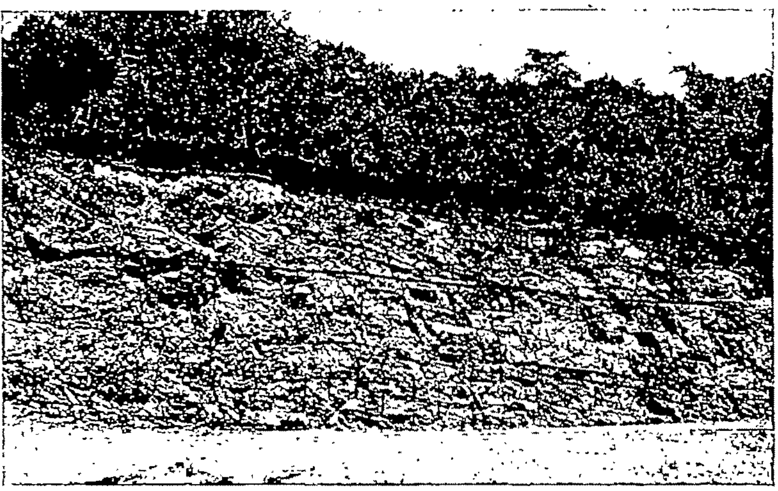

Fig. 6. Thrust in Devonian strata near Smith's Inn, south end of Becraft Mountain. Trace of thrust, shown by ink line in the photograph, is outlined by a calcite band. Coeymans strata above, New Scotland below.

Siluro-Devonian at Becraft Mountain.—Deformation of the post-Ordovician formations at Becraft is fully as severe as at Catskill, Rondout, or any other locality farther south in the Hudson Valley. The synclinal structure of the mountain indicates folding on a large scale, and flat thrusts testify to the severity of compressive forces acting from east to west. Thus there is no suggestion that the second Paleozoic deformation in this region dies out to the north. If the later formations were present to record its effects, no doubt this disturbance would be recognized much farther north than Becraft Mountain.

FORMER EXTENT OF DEVONIAN IN THE HUDSON VALLEY REGION.

Any geologist who travels up the Hudson River from Kingston to Albany on one of the day boats and looks west at the 4,000-foot pile of Devonian deposits, must wonder how far east these formations once extended. As the upper 2,000 feet or more are delta and brackish water strata (late Middle and Upper Devonian) and in the main fine-grained sandstone with local conglomerates, we are confident that their shoreline (Appalachian geosyncline) must have been restricted to the western side of the Taconian Mountains, and that these strata could not have united with the fossiliferous Devonian of the Connecticut Valley at Bernardston, Massachusetts, since the latter is of late Lower Devonian age and of another geosyncline. On the other hand, the lower half of the Catskill strata is largely limestone, and as some of the species of the Becraft, Oriskany, and Schoharie formations are also found in southern Quebec (Lake Memphremagog) and northern New Hampshire, and especially well preserved and in greatest numbers in Gaspé, we see that the seas of these times and places must once have been united, if we are to explain the faunal similarities.

Where was this connection? In the St. Lawrence Valley the most westerly occurrence for the Schoharie and Oriskany species is on St. Helen's Island at Montreal, but until the summer of 1931, not a trace of them had ever been found to the west of the Green Mountains in the Champlain-Saratoga-Hudson Valley and north of Albany and Becraft Mountain. During that summer, E. O. Ulrich found *Edriocrinus pociliformis* south of Milton, Vermont, indicating the presence of Lower Devonian strata in that deformed belt. Accordingly, it is most likely that the Lower Devonian sea of the Hudson Valley extended north to Montreal and thence down the St. Lawrence geosyncline to Gaspé and Newfoundland. On the other hand, the early Upper Devonian faunas of central and eastern New York have many forms of European origin, and these as well must have come down the St. Lawrence geosyncline. With this evidence at hand, we may well believe that much of the Devonian still preserved in the Catskill Mountains was represented all along the western side of the Green Mountains in Vermont. Finally at Bernardston, in the Connecticut Valley, which is east of the Green Mountain axis, unmistakable late Lower Devonian fossils have also been found and these have long been seen to belong to the marine faunas of the St. Lawrence geosyncline of Gaspé and Quebec. These deposits of Bernardston possibly were once connected across the eroded Taconian mountains with the Catskill mass of the Hudson Valley and with those of northern New Hampshire and of Gaspé farther east. Both these seaways were destroyed by the crustal elevations due to the Acadian orogeny of Devonian time, which culminated toward the close of this period. In the Gaspé area, it has been shown that this movement began late in the Lower Devonian. Since the thick clastic strata of the Catskill formation indicate as their source a highland of considerable magnitude in western New England, it is a logical conclusion that the Acadian movement again raised the area of the present Taconic Mountains and destroyed the marine portal of the St. Lawrence geosyncline as well.

Prindle now dates as probably early Cambrian the Rensselaer grit on the western side of the Taconic Mountains. This formation has been variously assigned by different geologists, but the recent tendency has been to consider it a remnant of the Catskill clastics, overlapping eastward. According to Prindle's evidence, which he will present in another place, this view is untenable. Whatever the correct disposition of the Rensselaer grit may be, however, it now appears probable, in view of Ulrich's discovery, that strata equivalent to the entire Catskill Mountain section once extended along the flanks of the Taconic and Green mountains into Quebec and down the St. Lawrence Valley. These strata have been removed by post-Devonian erosion.

THE CAPITAL DISTRICT.

Ruedemann (1930) has discussed the stratigraphy and structure of the Capital District (Albany, Cohoes, Troy, and Schenectady quadrangles). In a belt whose western boundary lies several miles west of the Hudson River, the Cambrian and

Ordovician formations are closely folded on axes trending east of north. The folds are overturned to the west, and slaty cleavage, dipping generally eastward, is strongly developed in the shales. Important thrust faults, inclined to the east, strike parallel to the folds. In the southwestern part of the district Silurian and Devonian strata, forming the Helderberg Mountains, lie above the deformed Ordovician; there is strong angular unconformity along the east base of the mountains, but the discordance becomes less pronounced to the west. The Silurian and Devonian formations are moderately folded, presumably as a result of the Appalachian revolution in late Paleozoic time.

Ruedemann attributes the severe folding, thrusting, and metamorphism of the Ordovician and Cambrian rocks to the Taconian orogeny, which "took place at the end of the Ordovician period, according to general assumption." This view is supported by the unconformity at the base of the Helderbergs, and Ruedemann sees further evidence in the eastern part of the district where the Rensselaer grit, which he assumes is Devonian in age, appears to be unconformable on Upper Cambrian and Ordovician strata. However, since Prindle now assigns the Rensselaer grit to the Lower Cambrian, possibly its base in the Rensselaer Plateau is marked by a flat thrust fault instead of an unconformity. Ruedemann's map itself suggests this thrust relationship. Therefore the severe deformation in the eastern part of the Capital District can be dated merely as post-Ordovician; how far it may be due to later Paleozoic movements rather than to the Taconian orogeny is now an open question.

TECTONIC HISTORY OF THE REGION.

The reality of Taconian deformation in the Hudson Valley is demonstrated by the facts discussed above. This belt of folding extends southwestward into Pennsylvania (Stose, 1930), and it is well known that late Ordovician folding and thrusting were severe along the St. Lawrence geosyncline in southern Quebec and Gaspé (Schuchert, 1930). Presumably, therefore, the belt of deformation was continuous from southeastern Pennsylvania to eastern Newfoundland, and in general the severity of the movement increased toward the northeast.

It is clear also that the rocks of the Hudson Valley were compressed again sometime after the Middle Devonian. Davis, Van Ingen, Ruedemann, and others have assumed that this later movement was contemporaneous with folding of the southern Appalachians, in the late Paleozoic. Perhaps this interpretation is correct; but we wish to emphasize that the direct evidence now available serves only to date the later folding as post-Middle Devonian. It is not inconsistent with the facts to postulate that the movement was part of the Acadian orogeny in southeastern Canada. Moreover, even if it could be shown that the later folding is "Appalachian" in date, it would not follow that the deformation in the Hudson Valley represents "the dying out of the Appalachian movement to the north," as some geologists have stated. Direct evidence of the later deformation has not been reported north of Becraft Mountain, but no outcrops of post-Ordovician strata have been found farther north in the folded belt of New York and Vermont. Keith, using the character of the flat thrusts as a criterion, has expressed his conviction that the intense deformation of Cambrian and Ordovician rocks in northwestern Vermont resulted during the Appalachian revolution (1923). According to this view the late Paleozoic movement extended much farther north than the Hudson Valley, but the effects are now seen only in the early Paleozoic rocks. Keith's position in this matter appears to be insecure; he completely ignores the probable rôle of the Taconian movement in western Vermont. However, the possibility cannot be denied that both the Acadian and the Appalachian movements made some contribution to the folding and metamorphism in western New England and eastern New York.

Although we have no new evidence bearing on these regional tectonic problems, we wish to help focus attention on the uncertainties that exist regarding the history of this important belt of complex geology. We are convinced that the Taconian movement played an important part in the deformation from southeastern New York to southern Quebec. But exactly what were the effects of the Acadian and Appalachian movements in this region? The great mass of Catskill sediments testify to important uplift along or near the Taconian axis in the later Devonian. Was this a simple warping, unaccompanied by folding and thrusting such as occurred in the maritime provinces during the same period? How severe was the Appalachian movement along the Taconian axis, and how far north did it extend? From the indirect evidence we incline to the view that the Silurian and Devonian of the Hudson Valley were folded in the late Paleozoic, as Davis and Ruedemann suggest; but even if this date were established, other important problems would remain.

E. B. Bailey has suggested (1928) that the deformation in western New England is of "Caledonian" date, and that the front of the "Hercynian" folded belt, swinging southwest from eastern Massachusetts, crosses the older belt in southeastern New York. This is an interesting speculation, and should be kept in mind by students of tectonics. At present, however, we see two serious objections to the view. The Acadian folding of Devonian time is taken to be the approximate equivalent in North America of the Caledonian in Europe, but as explained above, the Taconian movement, near the end of the Ordovician, appears to have played a much more prominent part than the Acadian disturbance in producing the structural features from the Hudson Valley to the lower St. Lawrence Valley. Moreover, we cannot see the slightest evidence, in trend lines or other structural features, that the later folding cuts across the earlier in southeastern New York.

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THE AGE OF A MONAZITE CRYSTAL FROM PORTLAND, CONNECTICUT.

CLARENCE N. FENNER.

Some time ago Professor Adolph Knopf sent to me a specimen of monazite from the Brush collection at Yale, of which an analysis should be of considerable interest; and at his request I undertook to carry this out.

The matter of special interest was the fact that this crystal was obtained from the same pegmatite deposit at Portland, Connecticut, as specimens of uraninite which W. F. Hillebrand had analyzed many years ago.[1] These analyses were made long before the possibility of calculating geological ages from the products of radioactive disintegration had been suggested; but inasmuch as determinations of uranium, thorium, and lead were made, the necessary data for such a calculation were at hand.

Even before the date of Hillebrand's publication S. L. Penfield[2] had made a study of the composition of monazites, and had published an analysis of a specimen from this same pegmatite, but for the purposes of age calculation this analysis was defective. Thorium was determined, but apparently lead and uranium were not looked for.

The possibility of being able to determine geological ages by calculations based on the principles of atomic disintegration of radioactive elements is regarded by most geologists as of great importance, but there are probably a number who still feel uncertainty or scepticism regarding the matter. This is doubtless due largely to certain improbable or discrepant results which have been published. Those who have made a careful study of the matter, however, are inclined to the opinion that while there is necessity for the exercise of judgment in the choice of proper material and for much care in analytical manipulation, the principle of the method is sound. Minerals which have undergone much alteration by weathering processes should be regarded with strong suspicion because of the likelihood of leaching or possibly concentration of the elements on which calculations are based; and analyses require careful attention both in the choice of methods and in actual work. Another factor, regarding whose importance there is still uncertainty, is the possibility of the presence of lead of non-radioactive origin deposited originally with the mineral. These and other matters have been fully discussed in the volume "The Age of the Earth," recently issued by a committee of the National Research Council.[3]

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[1] Hillebrand, W. F., On the occurrence of nitrogen in uraninite and on the composition of uraninite in general, U. S. G. S. Bull. 78, 43-79, 1889-1890.

[2] Penfield, S. L., On the occurrence and composition of some American varieties of monazite, this Journal, 24, 250-254, 1882.

The uraninites analyzed by Hillebrand are essentially uranium minerals with only minor amounts of thorium; the monazite is a thorium mineral which should carry little or no uranium. The presence of the two minerals in the same deposit should furnish a valuable means of checking the trustworthiness of calculations of age, for uranium and thorium respectively stand at the head of two independent lines of radioactive disintegration, each ending with lead. Calculations from each should give nearly identical results.

The quarry from which the uraninite and the monazite were obtained is the Hale Quarry, in the township of Portland, Connecticut. The site is a few miles east of north from Middletown, and just to the south of the Glastonbury township line. Some confusion in the literature has been caused by the fact that Hillebrand gave the origin of the uraninites analyzed by him as Glastonbury, although he stated definitely that they came from Hale's quarry.

The following information on the geology and mineralogy of the area is quoted from an article by W. G. Foye[4]:

"The Connecticut pegmatite dikes are composed of predominating quartz and perthitic feldspar with some muscovite and biotite. Most of the gem minerals occur in pockets from a few centimeters to over one meter in diameter. Some of the larger pockets have shown quartz crystals 6 decimeters long, and 3 decimeters in diameter. Perthite crystals with well-developed planes have equalled the quartz in their dimensions. These minerals project from the walls of the cavities, and are covered by platy crystals of cleavelandite which form a background for the rarer minerals.

"Eight of the fourteen localities occur in the Bolton schist, and four others lie within the Middletown series of metamorphic sediments which are closely allied to the Bolton schist. Only two localities are found in orthogneiss . . . . .

"Southward along the state road from Glastonbury there are a number of quarry openings. The only one which has produced rare minerals is the Hale or Andrews quarry . . .. The quarry is no longer worked, but in its day it was one of the best in the region. Large, well-formed monazite crystals (2 to 3 cm. in diameter) were found here, and are not known elsewhere in the district. Other minerals were molybdenite, sphalerite, rose quartz, zircon, columbite, massive green apatite, purple heterosite (secondary after triphylite), and uraninite. The uraninite analyzed by Hillebrand in 1889 was from this quarry. It will be noted that the quarry is within the limits of the town of Portland, not in Glastonbury, as stated in most references.[5] A single blast about the year 1884 yielded 100 kilograms or more of columbite, the largest single yield from one pocket known in this vicinity. The entire mass was without crystalline planes."

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[3] Knopf, Adolph, Chairman, Physics of the earth—IV, The age of the earth; Bull. No. 80, National Research Council, June, 1931.

[4] Foye, W. G., Mineral localities in the vicinity of Middletown, Connecticut, Amer. Min., 7, 4-12, 1922.

Foye attributes the intrusion of the pegmatites to the Appalachian mountain-building, but this appears to be an assumption. The age of the inclosing schists and gneisses also is uncertain. Rice and Gregory[6] state:

"No organic remains have been found in the crystalline rocks of eastern Connecticut, and so long as fossil evidence is lacking no definite statements can be made regarding the stratigraphic position of the different formations." However, "the discovery of fossils of the Carboniferous period in the Worcester phyllite [of Massachusetts], which is probably the equivalent of the Pomfret phyllite [of Connecticut], suggests a late Paleozoic age for most of the schists east of the Connecticut River."[7]

The monazite crystal received from Professor Knopf carried the identification number 479. Its weight was 19.85 grams. A very little mica and feldspar adhered to the outer surface. There was a very slight amount of surface decomposition, but most of the crystal appeared fresh and glassy or resinous, in color and luster much like brownish yellow amber. An accompanying thin section confirmed the impression of fresh character. Altogether it appeared in very good condition to give a trustworthy analysis.

As a precaution the parts of the surface that showed a film of decomposition were scraped off with a knife. Most of the crystal was then crushed to pass 100 mesh. The sieve used was one specially prepared by having the screen soldered to the frame with tin instead of the usual lead-tin alloy.[8]

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[5] For additional information on this point see B. B. Boltwood: On the ultimate disintegration products of the radioactive elements. Part 2, The disintegration products of uranium; this Journal, 23, 81, 1907.

[6] Rice, W. N., and Gregory, H. E., Connecticut Geological and Natural History Survey, Bull. No. 6, 2, 115, 1906.

[7] Rice and Gregory, op. cit., p. 114.

[8] This sieve has been used likewise in preparing samples previously reported on, on which determinations of lead for age calculations have been made.

The sample used for the lead determination weighed 5.9007 grams. It would have been much more satisfactory, in view of the small amount of lead expected, to be able to use 20 or 30 grams, but the small amount of material available imposed limitations. The method of analysis used was essentially that described in a previous publication.[9]

The analysis was made with much care, and proceeded without disturbing incident. The result obtained was

$$PbO = 0.1086\% \text{ or } Pb = 0.1007\%.$$

Penfield's determination of thorium[10] in monazite from this locality gave, in duplicate analyses, $ThO_2 = 8.33\%$ and 8.17%, mean = 8.25%. Since his specimen and mine might have slightly different amounts of impurity or might differ a little in original thorium content, it seemed desirable to repeat the determination. It was also very desirable to find whether uranium was present. Determinations of the two elements were made on a sample of 3.6767 grams. The methods used were only slightly modified from those given in my pamphlet previously cited. For the separation of thorium, a precipitation with oxalic acid was followed by three precipitations with hydrogen peroxide, and a final precipitation with oxalic acid. The amount of ThO_2 found was 8.52%. For uranium the separation by potassium ferrocyanide was used. At the end of this analysis a small speck was obtained, equivalent to 0.006% if it was all U_3O_8, but the color was dark reddish brown instead of olive-green and it was unaffected by warm dilute HNO_3. It seems, therefore, that uranium, if present at all, amounts to only a negligible trace.

The results may be summarized as follows:

$$\begin{array}{rlrl} PbO &= 0.1086\% & Pb &= 0.1007\% \\ U_3O_8 &= 0.00 & U &= 0.00 \\ ThO_2 &= 8.52 & Th &= 7.489 \\ 0.36\ Th &= 2.696 & & \\ 1.155\ Pb &= 0.1163 & & \\ \dfrac{Pb}{0.36\ Th} &= 0.037 & & \end{array}$$

For the calculation of age we shall use the formula given on page 99 of the previously cited publication of the National

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[9] Fenner, C. N., The analytical determination of uranium, thorium, and lead as a basis for age-calculations, this Journal, **16**, 369-381, 1928.

[10] Penfield, S. L., On the occurrence and composition of some American varieties of monazite, this Journal, **24**, 250-254, 1882.

Research Council, "The Age of the Earth," omitting the term L, which represents any ordinary lead (i.e. lead of non-radioactive origin) which may be present. We then have

$$t = \frac{\log\,[0.360\ \mathrm{Th} + 1.155\ \mathrm{Pb}] - \log\,[0.360\ \mathrm{Th}]}{6.60 \times 10^{-11}}$$
$$= 277{,}900{,}000 \text{ years.}$$

Hillebrand[11] made analyses of five separate specimens of "Glastonbury" uraninite, with two of the analyses partly in duplicate. Of these, he apparently attached most weight to No. 5, which was made after much experience with this mineral had been gained. He says of this:

> "A very large irregular crystal of this lot was crushed and purified as far as possible, and with this material a very careful analysis, duplicated in part, was made for the purpose of obtaining an accurate summation. This analysis post-dates all others published in this paper except No. XVIII."

This seems the most desirable one to use for age calculation. The data obtained from Hillebrand's work are:

	a	b	c	Mean
UO_3	23.13	22.94	....	23.03
UO_2	59.88	60.07	59.83	59.93
ThO_2	10.01	....	....	....
PbO	3.08	3.08	....	3.08

$U = 72.008$

$Th = 8.799$

$Pb = 2.859$

$0.36\ Th = 3.168$

$1.155\ Pb = 3.302$

$$\frac{Pb}{U + 0.36\ Th} = 0.038$$

Applying the same age formula as before we obtain

$$t = 282{,}900{,}000 \text{ years.}$$

Thus from the monazite we deduce an age of 277,900,000 years, and from the uraninite an age of 282,900,000 years. The agreement is highly satisfactory.

In the publication "The Age of the Earth," Professor Schuchert has discussed the correlation of geological periods with the available data on age determinations, and has placed the Portland ("Glastonbury") uraninite in the middle or, perhaps, late Devonian.[12] This is on the basis of its age in years, as determined by radioactive methods, in correlation with the gradually accumulating but still fragmentary evidence of ages found for the various geological periods in different parts of the world. As we have seen on an earlier page of the present article, evidence of purely geological character is not sufficient to offer more than a suggestion of middle or upper Paleozoic age for the enclosing Bolton schist, and nothing regarding the age of the pegmatite intrusion.

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[11] Hillebrand, W. F., op. cit., p. 62.

With regard to the last matter Barrell has said:

> "Granitic intrusions occur repeatedly in New England and appear to have covered quite a range in time, since Carboniferous formations rest in places upon somewhat older granites as well as being cut by those of younger age."[13]

This evidence of successive intrusions is of some importance in comparing the age of the Portland minerals with the age of a certain uraninite from Branchville, Connecticut. From Hillebrand's 3 analyses of Branchville material[14] an age of 388,000,000 years is indicated. The material is described by Hillebrand as brilliant and almost absolutely free from impurity. Unless lead of non-radioactive origin is present, for which there is no evidence, the uraninite from Branchville is much older than that from Portland. If it were not for the geological evidence of granitic intrusions at different periods, it might appear a somewhat disturbing circumstance that the ages of two uraninites from localities only about 50 miles apart should be found to be quite different. One seems to be Ordovician and the other Devonian.

A somewhat similar situation appears with regard to certain radioactive minerals from Brazil. An analysis made by E. P. Henderson on a polycrase from Tocantins, Brazil,[15] indicates an age of about 604,000,000 years, as calculated by the formula used in the present paper, while analyses made by me on a samarskite and on a monazite derived from a deposit at

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[12] Schuchert, C., op. cit., pp. 43 and 49. The age there given for this uraninite is 290,000,000 years, which may, perhaps, have been derived by using an average of Hillebrand's analyses, instead of the one to which Hillebrand himself attached most weight, which has been used in the present paper.

[13] Barrell, J., Rhythms and the measurements of geologic time; Bull. Geol. Soc. Amer., 28, 745-904, especially p. 862, 1917.

[14] Hillebrand, W. F., op. cit., p. 64.

[15] Hess, Frank L., and Henderson, E. P., Polycrase from Brazil, Jour. Frank. Inst., 200, 235-238, 1925.

Divino de Ubá indicate 355,000,000 years for one and 364,000,000 years for the other.[16]

In this instance the positions of the two occurrences, as shown by the somewhat indefinite descriptions available, are between 75 and 125 miles apart. The analyses indicate a late pre-Cambrian age for one and probably Silurian for the other. As evidence on such matters accumulates, and is checked by repeated determinations, and this, in turn, is correlated with geological evidence from other sources, we may hope to attain the very desirable goal of fixing the times at which periods of great igneous intrusion and orogenic disturbances have affected various areas. Many secondary results applicable to the interpretation of the geological record will then follow.

SUMMARY.

A crystal of monazite derived from a pegmatite at Portland, Connecticut, has been analyzed for uranium, thorium, and lead, with the following results:

$$\begin{aligned} U &= 0.00\% \\ Th &= 7.489\% \\ Pb &= 0.1007\% \end{aligned}$$

On the supposition that the lead has been derived from thorium by radioactive disintegration, an age of 277,900,000 years is calculated. This indicates a Devonian age.

Special interest is attached to this result from the fact that uraninite from the same quarry was analyzed by W. F. Hillebrand many years ago, and indicates an age of 282,900,000 years. The check is very gratifying, and gives additional support to the essential correctness and reliability of the principle by which the age of radioactive minerals is calculated.

Some of the subsidiary aspects of the matter are discussed.

Geophysical Laboratory,
Carnegie Institution of Washington.

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[16] Fenner, C. N., Radioactive minerals from Divino de Ubá, Brazil, this Journal, **16**, 382-391, 1928. The figures for age given above differ a very little from those of the original paper because of slightly different values for the constants of disintegration as adopted by the Committee on the Age of the Earth.

UPPER MOLARS OF CANIS ARMBRUSTERI GIDLEY FROM CUMBERLAND CAVE, MARYLAND.*

BRYAN PATTERSON.

Field Museum has recently acquired, by exchange with Mr. G. Eifrig of River Forest, Illinois, a small collection of mammalian fossils from Cumberland Cave near Cumberland, Maryland. This locality has yielded an interesting Pleistocene fauna upon which several papers have been written by Dr. J. W. Gidley. In one of these he described[1] a new species of extinct canid, *Canis armbrusteri,* on the basis of two lower jaws characterized by the greater relative depth of the jaw as compared with that of the wolves, by smaller canines, by more simple P_2 and P_3, by the presence of a posterior basal tubercle on P_4, and by the relatively larger heel of the carnassial. According to Gidley the teeth displayed a closer similarity to those of coyotes and jackals, than to those of wolves and dogs.

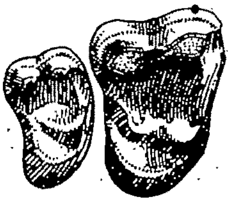

Fig. 1. Upper molars of *Canis armbrusteri* Gidley. Natural size. Drawn by Carl F. Gronemann.

Among the specimens received from Mr. Eifrig are the upper molars of a canid (F. M. N. H., No. P. 14790) which appear to be distinct from those of other North American Pleistocene and Recent species. Taking into consideration the fact that Cumberland Cave is the type locality of *Canis armbrusteri* and also that the teeth at hand agree in size with those of Gidley's type, the writer assigns them to that species. It appears worth while to place the specimen on record in order to facilitate identification and comparison, should an isolated skull or upper dentition of this species be discovered at some future date.

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* Published by permission of the Director, Field Museum of Natural History.

[1] Proc. U. S. Nat. Mus., 46, 98-102, Figs. 2-8, 1914.

Of the teeth acquired by Field Museum (Fig. 1) M^1 agrees fairly well in size with the type of *Aenocyon dirus* (Leidy)[2] from the vicinity of Evansville, Indiana, but is easily distinguishable from that form by the large size of the hypocone and by the greater size of M^2 when compared with M^1. On M^1 there is a fairly heavy external cingulum which continues around upon the side of the tooth to merge with ridges from the protocone and metaconule. The metacone is slightly smaller than the paracone, the transverse diameter of the latter being a little more than half the transverse diameter of the tooth. The protocone is relatively a little smaller than in the wolves of the *Canis nubilis* group, the metaconule is small but distinct, the protoconule has completely lost its identity in the ridge connecting the protocone and the external cingulum on the anterior side of the tooth. The hypocone is very large, being equal to more than one-fourth of the transverse diameter of the tooth. There is no ridge around the base of the protocone connecting the hypocone with the cingulum as in most other canids. This, however, may well be due to individual variation, as the absence of this ridge is sometimes noted in examining a series of teeth of recent dogs.

The second molar is relatively large, being over two-thirds the size of M^1. There is the same prominent external cingulum as appears on the first molar, but the paracone and the metacone are both relatively small. The protocone is small but distinct. The protoconule and the metaconule are indistinguishable but this is probably due, in some extent, to wear. The hypocone is very large, as on M^1, and is joined to the cingulum by a ridge around the base of the protocone.

Comparative Measurements of Upper Molars of *C. Armbrusteri, C. nubilis,* and *A. dirus.*

	C. armbrusteri	*C. nubilis*	*A. dirus*
M^1, greatest antero-posterior diameter ...	17.5 mm.	15.5 mm.	18.5 mm.*
M^1, transverse diameter of paracone	13 "	12 "	12.6 "
M^1, greatest transverse diameter	23 "	20.5 "	21.5 "
M^2, greatest antero-posterior diameter ...	11.5 "	8.5 "	10 "
M^2, greatest transverse diameter	17 "	12 "	14.9† "

* Tooth lacks the posterior enamel. Merriam, op cit., p. 233.
† Without enamel.

Gidley, in the paper cited, stressed the resemblance of P^4 and the lower carnassial of *C. armbrusteri* to the corresponding

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[2] Merriam, J. C., Mem. Univ. Calif., 1, 233. 1912.

DEVELOPMENT OF DRAINAGE OF CATSKILLS.

RUDOLF RUEDEMANN.

INTRODUCTION.

The writer has in a former article[1] described the development of the peculiar tangential drainage of the Adirondacks. The drainage lines of the Catskills are equally strange, indicating a long and intricate evolutionary history. A marked feature of this drainage is the circuitous course of the Schoharie River, the waters of which, rising within two miles[2] of the escarpment in the east, return within ten miles of their origin after following for 175 miles the four sides of a quadrangle by way of the Mohawk and Hudson Rivers; noteworthy, also, are the acute angle turns of the West and East Branches of the Delaware and their origin within a mile of the Schoharie River (see Fig. 1) and the tangential courses of the master-streams, the Hudson, Delaware and Susquehanna Rivers in regard to the Catskill cuesta.

To the writer's knowledge the cause of these strange phenomena has thus far not been sought. Guyot (1880, p. 443) in his pioneer work on the physiography of the Catskills comments on the remarkable fact that the Schoharie flows away from the escarpment of the cuesta towards the west and is flanked on the north (Catskill creek) and south (Esopus) by creeks that flow in opposite direction. He suggests "that the plateau of the Catskills had been lifted up on its eastern part to a higher level from which its waters were sent in the opposite direction." In a general way he sees in the horizontal position of the strata and long-continued erosion the two controlling factors. Especially he gives little weight to the discovery of Hall's assistants, announced by Hall in 1875, of four low anticlines pervading the Catskills in southwest-northeast direction in conformity with the Appalachian folding.

W. M. Davis' researches on the drainage of the Appalachian folds and on the folds at the foot of the Catskills (1882) are of fundamental import in the present work. He also empha-

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[1] Ruedemann, R., The Tangential Drainage of the Adirondacks, this Journal, 22, 431-440, 1931.

[2] The north branch rises 11½ miles, the south branch but 7¼ miles from the Hudson. They were still two miles nearer to the Hudson before the Kaaterskill and the Plaaterskill cut off that much from the headwaters by stream-piracy.

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sizes the fact (1896, p. 747) that the Potomac, Susquehanna, Delaware and Hudson are all abnormal in flowing from the Allegany plateau across the inner lowland and out through the oldland to the Atlantic, which abnormal courses had been attained in early Tertiary time.

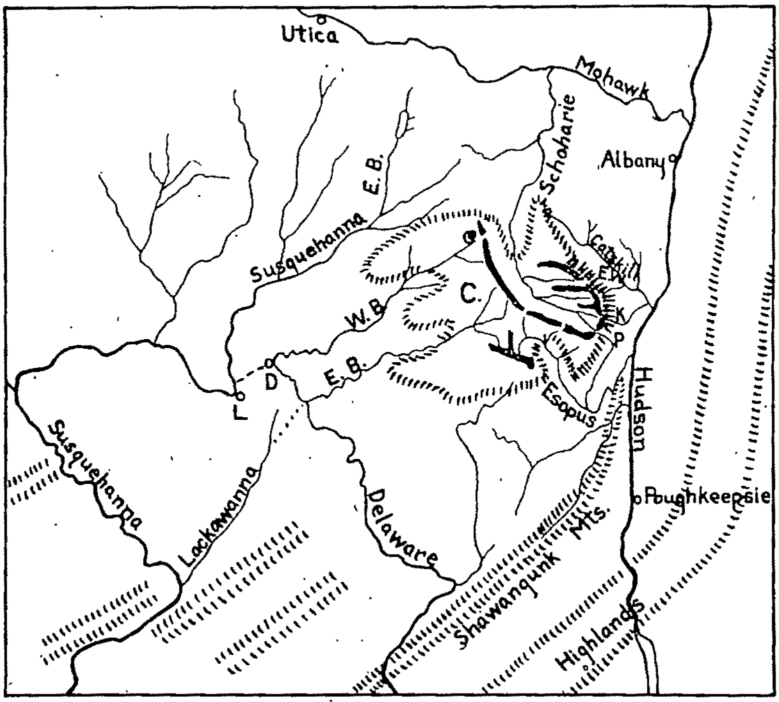

Fig. 1. Chart of the drainage of the Catskills and surrounding country. The Catskill plateau is indicated by hachures, the principal Catskill mountain ridges are in black. Abbreviations: C = Catskill Plateau; G = Grand Gorge; E. W. = East Windham; P = Plaaterskill; K = Kaaterskill; E. B. = East Branch; W. B. = West Branch; D = Deposit; L = Lanesboro.

An important discovery was the recognition of two cases of stream-robbery in the Catskills by Darton (1896). Thereby the new principle of stream-piracy was introduced into Catskill hydrography, in this case in reference to the headwaters of the Schoharie which have been cut off by the Kaaterskill and Plaaterskill.

Much new observational material has been furnished by Rich (1915), who points to the unilateral drainage of most tributaries, especially that of the Schoharie, and sees the cause of this phenomenon in the adjustment to the slight south and southwest dip of the rocks. Only Esopus creek has a dendritic, perfectly symmetric drainage pattern which would indicate horizontal beds in its case. He states that the Susquehanna and the Delaware flow in consequent courses down the dip toward the axis of the Paleozoic bay in which the rocks of the plateau accumulated. The Schoharie creek, he finds, is obsequent in its lower course, subsequent in its middle course and consequent in its upper course. The other rivers and creeks are mostly subsequent according fully with the structure (the cuestas, etc.). Rich also discusses the various peneplanes, the most notable of which is the 2,000-foot plain surrounding the Catskills. This has been termed the Cretaceous peneplane by Grabau (1906), while Davis (1891) suggests that the Cretaceous peneplane lies in the Catskills at about 2,500 feet. Barrell (1914, p. 104) would place the oldest peneplane on top in the Jurassic. As Rich remarks, further study is needed for the correlation of the several peneplanes recognizable. For us, the recognition of their presence in and about the Catskills is the important fact.[8]

Fairchild (1925, p. 26) recognized that the upper Delaware was once a tributary of the Susquehanna and pointed out the old connecting course between the West Branch of the Delaware and the Susequehanna between Deposit and Lanesboro, now used by the Erie railroad.

TECTONIC HISTORY OF REGION.

If we wish to reconstruct the history of the strikingly peculiar drainage of the Catskills, we have to go back to the condition of the country at the end of the Carboniferous period, when the last emergence of the area from the sea took place and the Appalachian mountains arose. There is no doubt, from the enormous erosion that since must have taken place, that on the Upper Devonian Catskill beds now forming the top must have rested thick deposits of Carboniferous age, a slight remnant of which is still indicated by a patch of conglomerate on Slide Mountain. If Chadwick's (1931) contention that the Catskill beds are mostly of Portage age is true, even greater erosion has taken place on top of the Catskills. These beds were dipping toward the southwest, or the center of the basin of deposition, as those of the Catskills still do to-day.[4] To the east of the Catskills the Appalachian folds arose, sweeping towards north-northeast, the roots of which are still displayed in the folded beds at the eastern foot of the Catskills, as about Kingston and Catskill. The Catskills themselves were slightly involved in this folding as announced by Hall, the Catskills lying in a broad, gentle synclinal trough, between the Adirondack uplift and its southern continuation

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[8] The three peneplanes of the Capital District have been recently discussed by the writer (1930, p. 19). They are the same as in the Catskill region. We consider the highest as the Kittatinny (Juro-Cretaceous) peneplane.

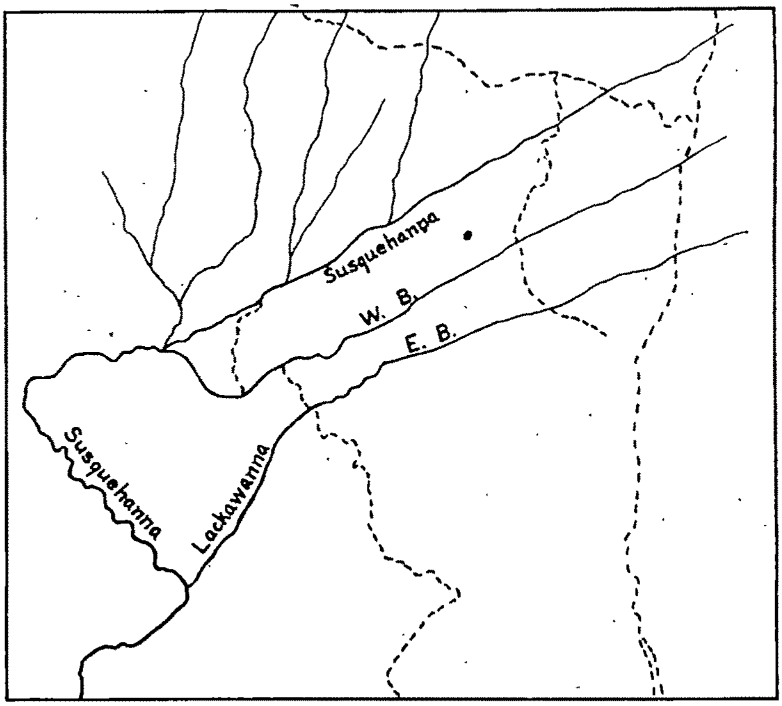

Fig. 2. Early stage of Susquehanna drainage in mesozoic time. Susquehanna headwaters reach upon the Adirondack plateau and eastern Appalachian mountain regions. Present drainage dotted.

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[4] The writer has not taken into account a possible tilting of the region, as there is no clear evidence of such save the post-glacial one. Especially there is no migration of divides recognizable that could be attributed to tilting.

and the Appalachian folds in the east and southeast with secondary anticlines running in the general direction of the Appalachian folding of the region. The general southward dip of the strata and the gentle syncline imposed upon the beds were the controlling factors of the first consequent drainage, directing it to the southwest (see Fig. 2).[5]

PRIMARY SUSQUEHANNA.

The Susquehanna and the West and East Branches of the Delaware (W. B. and E. B. on charts) and the upper Schoharie still follow this ancient course and may, therefore, be considered as relics of the original drainage. There is no doubt that these rivers once extended much farther to the northeast upon the original peneplaned surface, beyond the present course of the Hudson River and beyond the mountains rising east of the Catskills as indicated in Fig. 2. We may call this drainage that of the primary Susquehanna. Interesting evidences of this earliest drainage beyond the present Catskill cuesta are the broad, mature valleys of the two headwaters of the Schoharie extending right up to the escarpment in the east, where more recently stream-piracy from the east set in, and the broad pass at East Windham (E. W. of Fig. 1) across the northern ridge which, as pointed out by Rich, indicates an ancient river course. This is in the direct line of the East Branch of the Delaware and may well be the remains of the old Lackawanna-East Branch drainage line that reached out upon the Mesozoic plain.[6]

The Susquehanna has too long a course to the sea and a correspondingly low gradient. As a result it became the victim of stream-robbing first by the Hudson and Delaware Rivers and finally by the Schoharie.

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[5] Johnson has recently (1931) suggested that the Appalachian drainage may have been superposed from a coastal plain cover deposited on a very ancient peneplane of pre-Schooley (or pre-Kittatinny) age. This former extension of the Atlantic Coastal Plain may have amounted 125-200 miles beyond the present eroded inner margin of deposits. The assumption of such an ancient plain will also facilitate the explanation of the general course of the primary Susquehanna.

[6] There are two other well-known deep passes in the Catskills, the Stony Clove and the Deep Notch, both deep (1,800 feet below the adjoining mountains) and narrow valleys, breaking through the central ridge and connecting the Esopus and Schoharie drainages. Rich considers these as due to erosion by glacial waters.

PRIMARY HUDSON RIVER.

The Appalachian folds which trend in meridional direction east of the present Catskill cuesta and which were brought out by erosion from the Kittatinny peneplane allowed the formation of a river coming up from the nearer New York coast

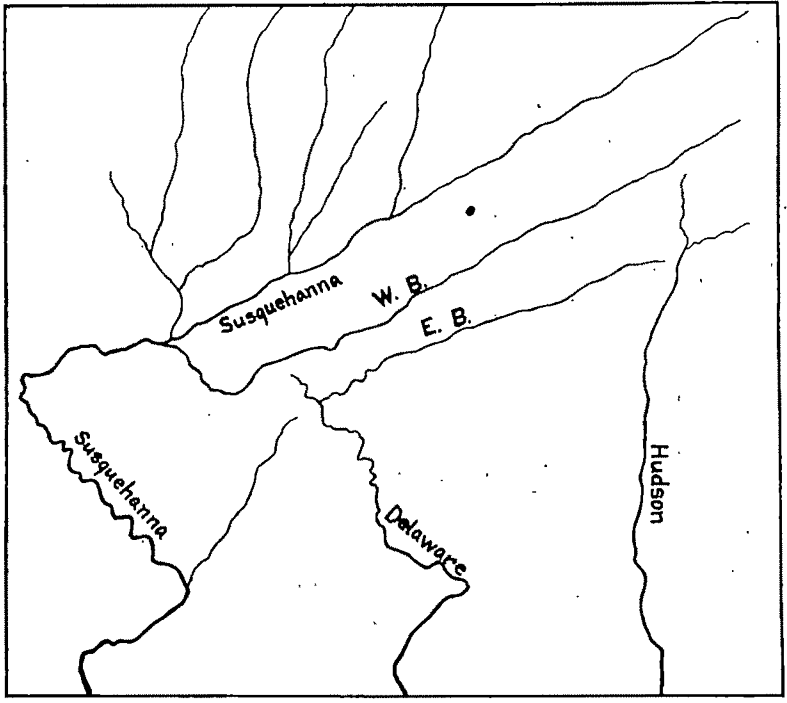

Fig. 3. Later stage. The Hudson has advanced far enough north to behead the East Branch in the east and the Delaware has captured the same stream in the middle.

(see Fig. 3) and developing a south-southwest course in the natural valleys between the folds.[7] This primary Hudson

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[7] Davis (1892) believes that the Hudson valley lowland which lies on either side of the narrow trench of the river bed was excavated during Tertiary times, being begun with the Juratrias-Cretaceous (Kittatinny) peneplane and having its course determined by irregularities of this plain rather than by the attitude of the markedly folded rocks out of which the peneplane has been formed by long denudation. Tarr (1902) points out that there are other possible hypotheses. We consider the middle course of the Hudson, which is following the trend of the Taconic and Appalachian folding, as largely controlled by this folding; the lower course, where the river breaks through the Highlands, is antecedent.

River had a much shorter course to the ocean,[8] steeper gradient and greater erosive power; it hence cut off the headwaters of the primary Susquehanna, first in the east (east of the Catskills) and finally in the north by its great tributary, the Mohawk (see Figs. 3 and 4).

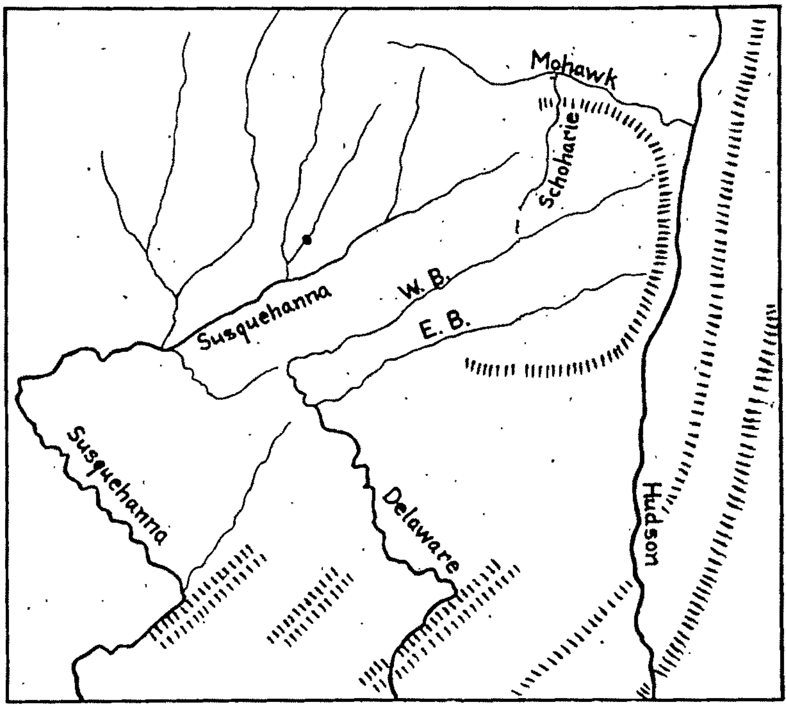

Fig. 4. A much later stage. The Hudson has reached the Adirondacks and sent the Mohawk westward, which in its turn is sending the Schoharie southward into the ancestral Catskill cuesta. The Delaware has captured the West Branch from the Susquehanna.

PRIMARY DELAWARE RIVER.

Together with the Hudson there developed still another river with a shorter course than the old Susquehanna to the south of the Catskills. That is the Delaware River which to-day has a course of only 375 miles as against the 500 of the Susquehanna and but 245 to tide, the latter ascending 130 miles to Trenton. While not as favorably situated as the Hudson, which besides comes to the foot of the Catskills with abundant water-supply from the Adirondacks, the Delaware has still only half the course of the Susquehanna to tidewater. The Delaware worked its way upward to the foot of the Catskill cuesta and cutting back northwestward (see Fig. 3) across the strike of the softer beds of the western Catskills succeeded in cutting off the tributaries of the primary Susquehanna which now form its West and East Branches. Fairchild (1925, p. 26) has already pointed out that a deep preglacial valley leads from Deposit (D on Fig. 1) where the West Branch makes its acute-angle turn in continuation of the West Branch course, to Lanesboro (L on Fig. 1) in the Susquehanna valley, a depression that has been made use of by the Erie railroad. Likewise the East Branch, when continued in its course beyond Hancock, leads directly to the upper Lackawanna making it probable that it also is a former branch of the old Susquehanna lost by stream-piracy to the Delaware. The headwater of the West Branch is to this day connected with the Schoharie by a deep broad notch at Grand Gorge (G of Fig. 1) which partakes of the nature of the wind-gaps of the Appalachians and, as noted before, the East Branch when continued leads to the broad pass at East Windham, also a wind-gap and ancient river-course leading beyond the Catskills.

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[8] The Hudson River is now, at Catskill, but 112 miles from New York Bay, while the sources of the Susquehanna are 500 miles from Chesapeake Bay. Moreover the Hudson is at tidewater at Catskill while the Susquehanna is not navigable from its mouth upward. It is, of course, unknown how much farther out these rivers once may have extended; if the submarine channel of some 60 miles is added to that of the Hudson, the much greater length of Chesapeake Bay has to be added to the pre-glacial Susquehanna course.

KITTATINNY PENEPLANE.

As denudation progressed in Mesozoic time, a peneplane, the Kittatinny, was finally established in early Cretaceous or possibly already in Jurassic time, remnants of which are still recognizable on the top of the Catskill Mountains. When the country was subsequently raised again, the Hudson River in the east and its tributaries were provided with new erosive power. They were able to lower the country to the north, east and south of the Catskills by two thousand feet, and to produce the two thousand-foot picturesque "mural front" at the east. The Catskill Mountain stock is now a subquadrangular cuesta (overlooking its subdivision into three parts by deep valleys) with high scarps bounding it at the northeast,

east and southeast, making that part in Guyot's words: "a mighty citadel overlooking by 2,000 feet all the surrounding country," while toward the west it sinks more gradually into the next lower peneplane. This high prominence of the eastern portion of the Catskill cuesta is due to the greater coarseness and resistance of the beds in the east than in the west. The Catskill beds were deposited in a delta of a late Devonian river coming into the Albany Bay (continuation of Clarke's Albany Bay of Portage age or still the same bay according to Chadwick) from higher land in the northeast. The writer (1930, p. 129) has concluded that the barren Rensselaer grit, forming the Rensselaer plateau east of the river with its irregular streaks of feldspar-bearing conglomerate, is a continental deposit of the stream that furnished the

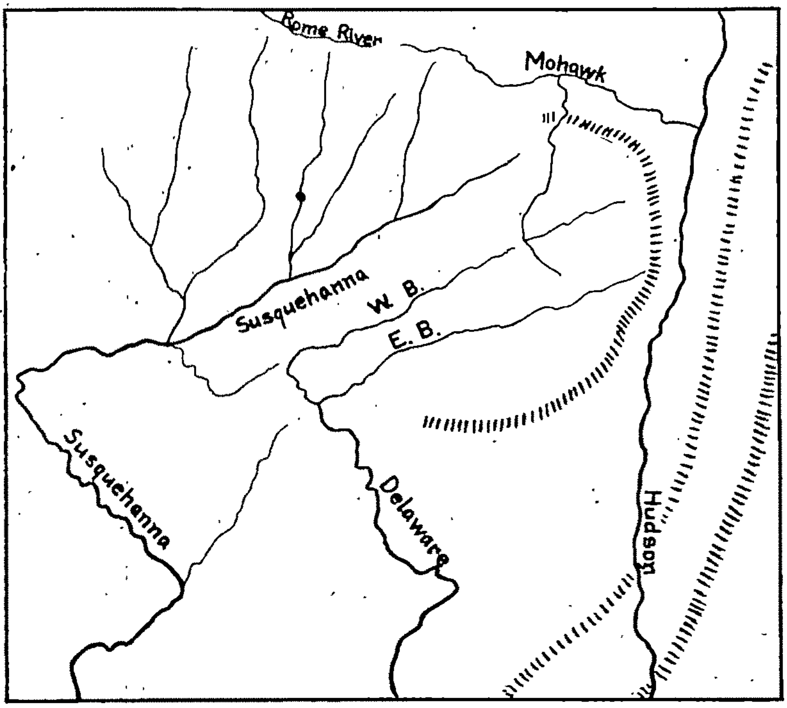

Fig. 5. The Schoharie has beheaded the West Branch of the Delaware and is proceeding towards the East Branch. The Mohawk and Rome Rivers are beheading the Susquehanna and its tributaries in the north.

material for the Catskill delta. If this view is correct, the coarseness of the material increased from southwest to northeast as it does yet in the Catskills and also beyond the present Catskill escarpment, but this coarser material succumbed to the Hudson River, leaving the eastward rising cuesta of the Catskills as a monument of the delta separate from the Rensselaer grit plateau in the east.

HARRISBURG PENEPLANE.

As denudation proceeded, a new erosion plane, the Harrisburg peneplane, was formed which completely surrounds the Catskill cuesta, at 2,000 feet being well recognizable in the Helderbergs and the Rensselaer plateau (see Ruedemann, 1930, p. 19). When again the country was raised in early Tertiary time, undoubtedly much above the two thousand feet now recognizable in the Harrisburg peneplane, as is indicated by the deep gorge of the Hudson River in the Highlands and its submarine course of sixty miles beyond New York Bay, the Hudson River received new erosive power and sunk its bed two to three thousand feet beyond this last peneplane, bringing the tops of the Catskills to a height of four thousand feet above tide-water almost at the foot of the mountains. The Hudson's mighty tributary, the Mohawk, was now able to send a branch, the Schoharie, southward through the Harrisburg peneplane into the Catskills. The broad valley of the Schoharie, 1 to 2 miles wide in places in the northern Catskills and in the Harrisburg peneplane, testifies to the age and former power of this stream. The Schoharie was able to cut off the headwaters of the Susquehanna and the Delaware, as is proven by the fact that it passes within a mile of the heads of the West and East Branches of the Delaware, having a typically asymmetrical or unilateral drainage pattern by lacking large tributaries on the south and west in the Catskills and thereby testifying to its piracy relationship with the Delaware and Susquehanna Rivers (Fig. 6). That the two headwaters of the Schoharie represent old courses now abruptly cut off by the eastern escarpment and once extending far out to the east of the Catskills is unmistakably shown by the fact that the two branches start, as already pointed out by Darton, in broad matured valleys that lie some 1,800-1,900 feet below the tops of the Catskill peaks north and south of them, while they themselves run out to the "mural front," where a 2,000 feet drop takes place (see Kaaterskill topographic sheet, Darton's figure and our Fig. 6). This is an entirely unnatural condition for the headwaters of rivers in mountain regions, where they normally are torrential and concave in outline and with declivities steepest in that section.

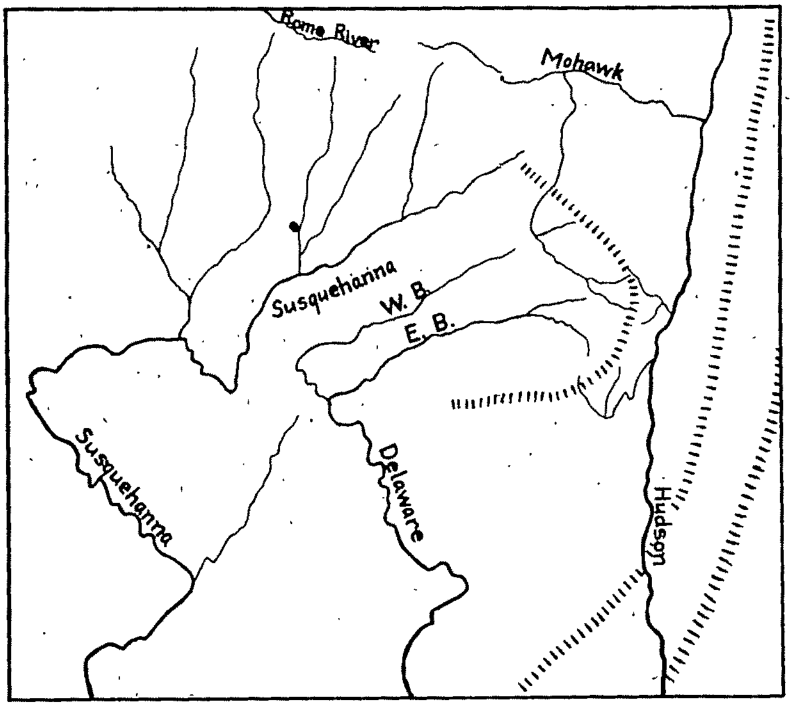

Fig. 6. The Schoharie has succeeded in capturing the headwater of the East Branch of the Delaware. The Catskill cuesta is approaching its present size. The small, steeply graded tributaries of the Hudson, east of the Catskills are advancing towards the mountains The last stage is shown in Fig. 1.

FINAL STAGE OF HISTORY.

The final stage in this curious history is that the Hudson River, which has reached so deep a level that it is an estuary with tides at the foot of the Catskills and as far up as Troy, is now sending from the east new shorter, very steep rapidly eroding streams into the Catskills, such as the Kaaterskill, Plaaterskill and Esopus which proceed to cut off the Schoharie and East Branch of the Delaware. Darton has already well described the stream-piracy that has taken place between the Kaaterskill and Plaaterskill on one hand and the Schoharie on the other.

These brooks have besides their steep gradients the advantage over the westward flowing streams of eroding against the dip and of thereby being able to take full advantage of the alternating harder and softer beds, rapidly removing the red shales and undermining the sandstones. This advantage is strikingly shown by the extremely high falls (Kaaterskill Falls, Haines Falls and Plaaterskill Falls) with which these rather insignificant brooks begin, and by which they have the advantage of a drop of two thousand feet within the first 1 to 2 miles of their course (see Fig. 1).

STREAM-PIRACY THE CONTROLLING FACTOR.

It thus seems that the entire abnormality of the Catskill drainage can be explained by systematic stream-piracy that proceeded first from the south and east and finally also from the north against the old consequent Susquehanna drainage, transforming the original symmetric southwest drainage into a more or less asymmetric north and south drainage.

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THE CRISTOBALITE STRUCTURES:
I. HIGH-CRISTOBALITE.

TOM. F. W. BARTH.

PREVIOUS WORK.

The stable form of silica between 1470° and 1710° is the high temperature modification of cristobalite, which in a metastable condition persists down to around 230°, where it undergoes an inversion. This inversion is readily reversible. The high temperature modification, called by Wyckoff[1] β-cristobalite, should, according to the now accepted way, preferably be referred to as the α-form; however, in order to avoid any confusion in this respect, the self-explanatory terms high- and low-cristobalite, suggested by Sosman,[2] will be used in this paper.

The crystal structure of high-cristobalite was proposed by Wyckoff[1] several years ago and is based on data obtained from powder spectrograms of devitrified silica glass taken above the inversion point. Wyckoff found that the unit cube contained 8 molecules of SiO_2 and that the space group criteria were in agreement with a face centered lattice having the symmetry of Fd3m, with the silicon ions in (8f) and the oxygen ions in (16b). The intensities calculated for this arrangement were not in perfect agreement with the observations; however, since the scattering powers of the ions were very inadequately known at that time, Wyckoff thought that these discrepancies did not cast any doubt on the structure, but rather that the underlying assumptions for the intensity calculations were wrong. He therefore changed the assumptions and was able to show that the calculated intensities are matched by the observations if the scattering power of silicon is taken to be from 2 to 5 times higher than that of oxygen.

INCORRECTNESS OF THE PREVIOUSLY PROPOSED STRUCTURE.

Our knowledge of the scattering of X-rays by crystals has rapidly increased in recent years. The intensity of a reflection from the face of a mosaic crystal[3] is given by the expression

$$\rho = K \frac{1 + \cos^2 2\theta}{2 \sin 2\theta} F^2,$$

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[1] Wyckoff, R. W. G., this Journal, **9**, 448, 1925.
[2] Sosman, R. B., The properties of silica. (New York, 1927.)
[3] Bragg, W. L., and West, J., Zeit. Krist., **69**, 118, 1928.

In this equation we are not interested, in the present case, in the value of the proportionality factor, K, because the absolute intensities from cristobalite can not be measured. F is the structure factor:

$$F = \sum_n F_n e^{2\pi i(hx+ky+lz)},$$

and the atomic reflecting power, F_n, or the F-values of the ions in silicates have very accurately been fixed by Bragg and his co-workers.[3] These F-values show that it is not permissible to make the assumption used by Wyckoff regarding the high scattering power of the silicon ions, and in view of this it became of interest to recalculate the intensities of the reflections from cristobalite, using the new F-values.

The intensities recalculated in this way are given in the fourth column of Table 3, while the observed intensities are given in the second and third columns. Obviously the agreement is not perfect[4]: for instance, a faint reflection from the face (400) is present in the spectrogram although the calculated intensity of this reflection is zero: the F-values for Si and O are 8.2 and 4.1 respectively, and the structure factor reduces itself to

$$F = 8F_{Si} - 16F_O = 0.$$

It is also worth noting that the distance Si-O calculated from the structure assigned by Wyckoff to high-cristobalite is smaller than usual (see Table 1).

TABLE 1.

Interatomic Distances in Ångstrom Units.

Crystal	Si-O
Cristobalite	1.54
Beryl	1.58
Diopside	1.61
β-Quartz	1.62
Titanite	1.64

These facts led to a re-examination of the structure of high-cristobalite, and it was found that in new spectrograms a few very faint lines which do not belong to a face-centered structure were present. Most prominent among them is probably the reflection from (023).

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[4] Although the discrepancies are small they seem to be significant; this is especially well brought out by a study of silicates isomorphous with cristobalite (see Barth and Posnjak, Zeit. Krist., 81, 135, 1932).

These observations indicate that the underlying lattice of the cristobalite structure is not a face-centered one, but a simple lattice in which, however, the ions are located in such a way as to approach the configuration of a face-centered lattice. Since the calculated intensities from the arrangement (8f), (16b) are so close to the observed values, it may further be concluded that the positions of the ions can not be very far from (8f), (16b). The great difficulty in carrying further the analysis of this structure lies in the fact that the experimental data have to be taken from powder spectrograms only, no good single crystal of cristobalite being available. Devitrified silica glass was used, and Dr. E. Posnjak kindly furnished me with some excellent powder spectrograms taken at different temperatures, from room-temperature up to 500°.

THE ACTUAL STRUCTURE OF HIGH-CRISTOBALITE.

The length of the edge of the unit cube, which comprises 8 molecules of SiO_2, was found to be 7.16 Å at 500°. All the cubic space groups based on a simple lattice had to be considered. By applying space-group criteria several of them could be ruled out, and several others were ruled out because a chemically plausible arrangement could not be found. Eventually only two remained, $P4_13$ and $P2_13$, which offered some hope of solution. However, calculations showed that no atomic arrangement in $P4_13$ could account for the observed intensities and thus $P2_13$ remained finally as the only possibility.

The space group $P2_13$ has only two sets of equipoints:

(4f): $u, u, u;\ u+\frac{1}{2}, \frac{1}{2}-u, \bar{u};\ \bar{u}, u+\frac{1}{2}, \frac{1}{2}-u;\ \frac{1}{2}-u, \bar{u}, u+\frac{1}{2},$

and 12 general positions as follows.

$x\ y\ z;$	$x+\frac{1}{2}, \frac{1}{2}-y, \bar{z};$	$\bar{x}, y+\frac{1}{2}, \frac{1}{2}-z;$	$\frac{1}{2}-x, \bar{y}, z+\frac{1}{2};$
$z\ x\ y;$	$\bar{z}, x+\frac{1}{2}, \frac{1}{2}-y;$	$\frac{1}{2}-z, \bar{x}, y+\frac{1}{2};$	$z+\frac{1}{2}, \frac{1}{2}-x, \bar{y};$
$y\ z\ x;$	$\frac{1}{2}-y, \bar{z}, x+\frac{1}{2};$	$y+\frac{1}{2}, \frac{1}{2}-z, \bar{x};$	$\bar{y}, z+\frac{1}{2}, \frac{1}{2}-x.$

By dividing the 16 oxygen ions associated with the unit cube into two groups: one group, O_I, in the 12 general positions with parameters x, y, z, and another group, O_{II}, in (4f) with parameters v; and dividing the 8 silicon ions into two groups: one, Si_I, in (4f) with parameter u_1, and the other, Si_{II}, also in (4f) with parameter u_2, an atomic arrangement similar to that of (8f), (16b) can be produced.

The process of finding the correct values for the parameters involved in the structures is very tedious; trial-and-error methods have to be used, and previously established atomic radii were employed to narrow down the possibilities.

Since the atomic arrangement can not differ very much from that proposed by Wyckoff, it was believed that the positions of the heaviest atoms, the silicons, should be close to the equipoints of (8f). Such an arrangement is produced by assigning to the parameters of the silicon ions, u_1 and u_2, a value equal to 90° and 0° respectively.

A region around these positions with all the corresponding values for x, y, z, and v that would lead to a tetrahedral arrangement of the oxygens around each of the silicon ions was investigated. During this work the inadequacy of the experimental data was badly felt; thus the failure of the powder spectrogram to resolve reflections from different faces having the same interplanar spacing, of which there are many in this point group, was an especially disturbing difficulty.

It was finally found, however, that the best agreement between the observed and calculated intensities is obtained by giving the parameters the following values:

$$x = 0.660, \quad y = 0.660, \quad z = 0.062$$
$$v = 0.125, \quad u_1 = 0.225, \quad u_2 = -0.008.$$

Calculations show that a change of 5° in the oxygen parameters, or a change of 3° in the silicon parameters spoils the agreement between calculated and observed intensities. The probable error in the values for u_1 and u_2 may consequently be estimated to be ± 0.008, and in the other parameters ± 0.015.

Table 2 gives the calculated and observed intensities of the reflections of the 24 simplest faces of cristobalite. Since the F-values of the oxygen ions decrease with decreasing spacings, and the positions of the oxygen ions are the ones differing most from the face-centered arrangement, it is improbable that any of the more complex faces can give rise to reflections that do not belong to a face-centered structure.

Table 3 gives the calculated intensities of all the more prominent reflections (those belonging to a face-centered lattice) compared with the intensities that should have appeared if Wyckoff's structure had been correct, and gives also for comparison the observed intensities. The agreement between calculation and observation is as good as could be expected; the small discrepancies may easily be accounted for by small errors in the parameter values.

TABLE 2.

Calculated and Observed Intensities of the Reflections of the 24 Simplest Faces of High-Cristobalite.

(Mo-radiation MoKα = 0.710 Å.)

Indices	$\frac{F^2}{1000}$	Frequency	Observed Intensities
011	.02	12	0
111	12.30	8	10+
002	.02	6	0
021	.14	12	0
201	.21	12	
211	.35	24	0.5
220	4.70	12	8
221	.25	24	0
031	.01	12	0
013	.53	12	
113	.30	24	1
222	3.10	8	3
023	.88	12	0.5
203	.32	12	
123	.30	24	0
213	.20	24	
400	.88	6	0.5
041	.13	12	0
401	.17	12	
223	.04	24	
411	.34	24	0.5
033	.00	12	
133	3.65	24	6
024	.01	24	0

TABLE 3.

Intensities of the Most Prominent Reflections from Cristobalite. (Mo-radiation.)

Indices	Intensities			
	Observed		Calculated	
	(Wyckoff)	(Barth)	from arrangement [8f], [16b]	from arrangement [4f], $[T^4(12)]$
111	20	10+	16	18.4
220	9	8	5.2	6.2
113	2.5	1	0.2	0.7
222		3	3.1	2.4
400	trace	0.5	0.0	0.4
133	7	6	6.0	6.0
224	6	5	3.6	5.0
115 333	2	2	0.4	1.5
440	3	3	3.8	3.2
135	5.5	3	4.2	4.5
206	2	2	1.8	2.1

The calculations compiled in Tables 2 and 3 show conclusively that although the atomic arrangement of high-cristobalite approaches a configuration having the holohedral symmetry of the cubic system, the actual symmetry is that of a tetartohedral cubic crystal.

DISCUSSION OF THE STRUCTURE.

In the cristobalite structure 4 oxygens form a tetrahedral arrangement around each silicon, but each of these oxygens is held in common by similar adjacent groups conforming with the two to one ratio of oxygen to silicon atoms. The tetrahedra thus linked together by shared oxygen ions form endless chains parallel to the directions that correspond to the six 2-fold axes in a holohedral cubic crystal.

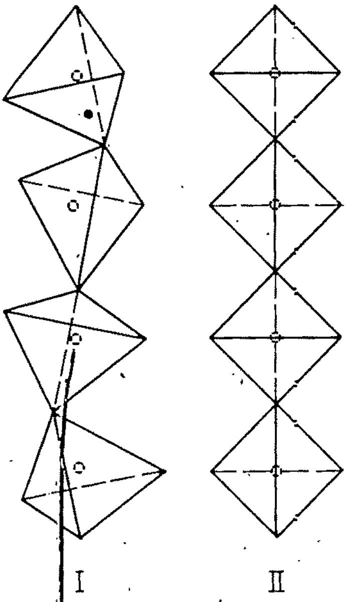

Fig. 1. Actual structure of high-cristobalite compared with the structure proposed by Wyckoff.

I. A piece of a silicon-oxygen chain projected on the (100)-face: The dotted circles are silicon ions; the oxygen ions are located in the corners of the irregular tetrahedra surrounding the silicons.

II. The same silicon-oxygen chain as it would have appeared if the atomic arrangement had been (8f), (16b).

In the structure proposed by Wyckoff these directions are actually axes of two-fold symmetry, and the silicon-oxygen chains would appear as pictured in Fig. 1, II, each silicon being surrounded by 4 oxygens in the corners of a regular tetrahedron. In the actual structure, however, these directions no longer represent the axes of two-fold symmetry; the silicon-oxygen chains are more irregular in shape, as shown in Fig. 1, I: the silicons are still surrounded by 4 oxygens but the tetrahedron is distorted so as to form a trigonal pyramid. As already explained, there are two groups of structurally equivalent oxygen ions, and two groups of structurally equivalent silicon ions, and the interatomic distances are as follows:

$\mathrm{Si_I - O_I = 1.58}$ Å
$\mathrm{Si_I - O_{II} = 1.62}$ "
$\mathrm{Si_{II} - O_I = 1.69}$ "
$\mathrm{Si_{II} - O_{II} = 1.64}$ "
Mean distance: $\mathrm{Si - O = 1.63}$ "

These distances are in good agreement with the interatomic distances usually found in silicates (see Table 1).

The X-ray spectrograms used in the present study were prepared at elevated temperatures in a specially constructed camera by Dr. E. Posnjak, who kindly placed the films at the author's disposal.

SUMMARY.

The crystals of high-cristobalite have previously been recorded as having the symmetry of the space group Fd3m (O_h^7), with the atomic arrangement (8f), (16b). Contrary to this determination it has now been found that the symmetry is that of $P2_13$ (T^4). The unit cube has 8 molecules of SiO_2. There are two groups of oxygen ions: O_I in the 12 general positions of T^4 with parameters x, y, z, and O_{II} in 4f with parameter v. There are also two groups of silicon ions, Si_I and Si_{II}, both of them in (4f) with parameters u_1 and u_2 respectively.

$x = 0.660, \quad y = 0.660, \quad z = 0.062$
$v = 0.125, \quad u_1 = 0.255, \quad u_2 = -0.008$

The interatomic distances are as follows:

$\mathrm{Si_I - O_I = 1.58}, \quad \mathrm{Si_{II} - O_I = 1.69}$
$\mathrm{Si_I - O_{II} = 1.62}, \quad \mathrm{Si_{II} - O_{II} = 1.64}.$

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MAGMAS FROM SUBSIDENCE.

J. S. DeLURY.

INTRODUCTION.

Igneous intrusions are commonly regarded as being incidental associates of a general crustal unrest. Geologists are still concerned with the question as to whether magmas rise more or less passively, or are driven into the crust with such force that they are important agents of deformation. Is the batholithic intrusion under a folded region a cause of folding, an effect of folding, or are both folding and intrusion concomitant effects of the same cause? The writer presents an hypothesis which favors the last interpretation and ascribes the cause to crustal subsidence.

Igneous rocks generally show in their structural relations, that their intrusions were associated with more or less pronounced crustal disturbance. In certain cases surrounding deformations were obviously made by the forces of the intrusion. This is particularly true of laccoliths and sheets. Many batholiths convey the same impression. Batholiths, moreover, commonly have associated and connected satellitic bodies, the force for the intrusion of which presumably came from the batholithic magma. It is not improbable that many igneous bodies, which have been assumed to have risen passively through lack of evidence to the contrary, actually exerted great intrusive force. For instance, the roof over a laccolith may show locally no indications of the great thrust which undeniably forced the intrusion.

Certain general features of the earth's crust suggest very strongly that deformations have been accomplished, in large measure at least, by igneous intrusion. Generally speaking, structures in the outer crust have been determined by the activities of the sub-crust. Most geologists will concur in the view that the sub-crust, beneath the veneer of sedimentary formations, consists almost entirely of igneous rocks which have been intruded within the span of geological history.

The writer has accordingly been led to the view that igneous intrusion must make space for itself, and in so doing, it effects a deformation of adjacent portions of the crust. And further, in view of the probability that the sub-crust is largely igneous rock, the conclusion is drawn that igneous intrusion has been a direct agent of crustal deformation. The same line of reasoning is opposed to the common conception of a primary and quiescent magma-chamber or magma-reservoir, in which the processes of magmatic differentiation may operate quietly and effectively for indefinite time.

The principle of differentiation is seriously overtaxed to explain the many associations of divergent rock types in flows and intrusions, and to explain why batholiths, derived from the so-called primary magma-reservoirs and showing little or no differentiation, have associated with them lavas and satellites of diverse composition. Some of the difficulties of the differentiationists are indicated in a quotation made by Holmes[1] from a summary supplied by H. H. Thomas in the *Ardnamurchan Memoir*:—

> " 'The origin of composite sills and dykes has always been a difficult problem, a final solution of which has not yet been found. Judging by the form and relations of the rocks involved, however, there appears to be no reasonable doubt of the simultaneous availability of two compositionally different magmas and of their coexistence in the same magma-reservoir, one magma following upon the other along the same fissure after a short interval of time, before the first had an opportunity to solidify completely . . . . . . Dr. Harker, on the evidence of the composite intrusions of Skye, considered it beyond doubt that the magmas responsible coexisted in subterranean reservoirs, and that the lighter acid magma overlay the denser basic one.' "

It is considered, as well, that the differentiation principle, because it has seemed to be the guiding one in untangling the puzzle of diverse rock types, has gained so much prestige in this direction, that it has dictated too much outside its proper field. The principle seems to call for properly disposed magma-chambers and for passive intrusion. It tends to make igneous intrusion an incident in crustal unrest, whereas this intrusion may be the prime factor. In short, the differentiation principle, while it has been a blessing in its own field, may not have been an unmixed blessing in its dictation as to what should be, in the wider province of crustal mechanics.

SUMMARY AND OUTLINE.

The writer presents in this paper an hypothesis that seems to eliminate some of the difficulties which, it has already been suggested, are inherent to current hypotheses of magma-formation, magma-intrusion and the explanations of the occurrence and association of divergent rock types. The hypothesis, moreover, besides seeming to meet the demands of igneous geology, appears to lead to a logical inter-relation of all crustal phenomena.

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[1] Holmes, A., The Association of Acid and Basic Rocks in Central Complexes, Geol. Mag., June, 1931, p. 243.

The principle of isostasy is considered to imply a horizontal migration of material at depth to account for the changes of level which have taken place throughout geological time. The zone through which isostatic compensation is effected, is conceived to be a relatively thin one, and being thin, the material of the zone may move horizontally for great distances. The great earth movements are regarded as being due to distortion of the earth as a whole or of the outer shells of the earth. Subsidence of large areas follows distortion and supplies the heat and other energy for a horizontal sheet-zone of flow. The migration of material through this medium of isostatic adjustment, as a plastic or highly viscous flow, brings about magmatic intrusion and elevation in other areas. Igneous intrusion and sheet-flow are considered to be the directing factors in all of the major phenomena of the earth's crust.

The existence of earth-distortion leading to subsidence and consequent sheet-flow permits a plausible explanation of the major structures and phenomena of the crust. The folding and batholithic intrusions of mountain regions are predictable effects. Overthrusting for horizontal distances of hundreds of miles is not unexpected. If the mechanism be admitted as possible, it is not difficult to offer an explanation of the formation and fragmentation of continents. An earth perfectly zoned and uniformly submerged by water might become distorted and so evolve into its present form.

The broader implications and applications of the hypothesis were outlined recently in a paper[2] by the writer. The present paper is written primarily to point out the probable importance of subsidence in the problems of magma-formation and igneous intrusion. Certain inferences will be drawn concerning the bearing of the hypothesis on the questions of differentiation and assimilation. The strength of the conception as a whole, however, lies in its broad correlation of all crustal phenomena, so that its implications in other directions will be briefly indicated.

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[2] DeLury, J. S., The Auto-traction Hypothesis of Crustal Evolution, Contrib. from the Dept. of Geol. and Mineral., University of Manitoba, Winnipeg, March, 1931.

SUBSIDENCE AND ELEVATION.

Throughout geological history many large portions of the crust have been going up and down. This statement, of course, does not admit the remote possibility that all movement has been downward and that apparent elevation is accounted for by differential subsidence. There is a general opinion, with much evidence to support it, that great portions of the ocean bottoms have subsided and that the continents have been elevated more or less at the expense of this subsidence.

In speaking of the movements which have increased the inequalities of the surface of the lithosphere, Chamberlin and Salisbury say:

> "With each such movement apparently, the oceans have withdrawn more completely within the basins, and the continents have stood forth more broadly and relatively higher, until again worn down. This renewal of inequalities appears to have been, in its great features, a *periodic movement*, recurring at long intervals.[3]"

The same authors again say, in writing of the time of origin and of the constancy of ocean basins:

> ". . . . . the ocean basins have probably been extended and the continents restricted."[4]

There is a very prevalent opinion expressed in geological literature that mountain-folds are produced by thrusts from the basins of neighboring oceans. The disappearance of borderlands along the Atlantic and Pacific coasts of America is very significant in this connection.[4a]

There is good evidence that during Cenozoic time, at least, the Pacific basin has been a subsiding area. The subsidence theory of coral reefs and atolls was first formulated by Charles Darwin. It was much developed by J. D. Dana. For several decades the theory was thought by many geologists to be supplanted by rival theories. The Darwin-Dana theory of subsidence has fortunately been reanimated and substantiated through the genius and efforts of W. M. Davis.[5] The indicated subsidence of hundreds, or perhaps thousands, of feet of some portions of the Pacific floor, may be in part due to local isostatic adjustment, but in view of other circumstances it is probable that there was a great general subsidence.

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[3] Geology, Vol. I, p. 539.

[4] Ibid, p. 545.

[4a] Auto-traction and the Formation of Batholiths. J. S. DeLury. (In press.) Trans. Roy. Soc. Can. 1931.

[5] The Coral Reef Problem, 1928.

The most certain evidence of elevation and subsidence throughout geological time comes, however, from the continents. Great areas have gone up and down several times during the earth's history. Vertical movements are commonly in hundreds, and sometimes in thousands of feet. General elevations in the continents are reflections of depressions in ocean basins. It is difficult to conceive of great changes of level like those just cited, without invoking distortion of earth or crust as a source of energy. Current explanations of mountain-folding leave much to be desired and those offered for plateau-formation carry no conviction.

ENERGY FROM SUBSIDENCE.

Great subsidences must be admitted. When an area of the crust subsides, energy is released. Possibly some of this energy is absorbed in chemical or physical change, with which a rise of temperature is not involved, but such changes are probably very limited. It is more likely that the energy of subsidence is converted into heat. On this assumption the calculations of the heat equivalent of subsidence, contained in the accompanying table, were made. Certain quantities required for the calculations are not precise enough to permit a high degree of accuracy in the results submitted. The heat of solution (latent heat of fusion ?) of average rock material is taken to be approximately 100 calories per gram. It is assumed that a cubic foot of rock in the subsiding mass weighs 180 pounds (corresponding to a specific gravity of 2.88), and that the specific gravity of the material where liquefaction takes place is 3. No account is taken of the variations of gravity with depth and latitude. The figures in the table are based on the assumption that subsidence effects liquefaction at the base of the subsiding mass and that the temperature of liquefaction exists there.

Liquefaction from Subsidence.

Thickness of crust in miles	Thickness of Sub-crust Liquefied In subsidence of 10 feet	 In subsidence of 100 feet
1	0.36 feet	3.6 feet
10	3.6 "	36 "
20	7.2 "	72 "
30	10.8 "	108 "
40	14.4 "	144 "
50	18 "	180 "

If the average specific heat of rock material, before and after liquefaction, be taken as 0.25 gram-calorie, it is simple to adapt the table to take into consideration the heating effect along with the liquefaction. For example, a crust 50 miles thick and subsiding 100 feet, produces heat enough to warm and liquefy a subjacent thickness of about 90 feet of rock which before the subsidence has a temperature 400° C. below that of liquefaction. Similarly, if the basal rock, before subsidence, were at a temperature near that of liquefaction, 90 feet would be liquefied and superheated 400° by the subsidence.

ADJUSTMENTS FOLLOWING SUBSIDENCE.

Under a subsiding area space must be made for the subsiding mass. How is the yielding accomplished? Is the whole earth affected or only the outer zones? An early view held that the earth is formed of great segments, corresponding more or less to the ocean-basins and continents, and that adjustments were made at great and unknown depths. The interactions of these segments were regarded as the prime cause of major crustal movements.

> "The downward movements are unquestionably the primary ones, and the horizontal ones are secondary and incidental. The fundamental feature is doubtless central condensation actuated by gravity, and the master movements are the sinkings of the ocean-basins. The great periodic movements that made mountains and plateaus, and changed the capacity of the ocean-basins, probably started with the sinking of part of the ocean-bottoms . . . . . . The squeezing up of the continents doubtless took place simultaneously with the settling of the basins. The true conception is perhaps that the ocean-basins and continental platforms are but the surface forms of great segments of the lithosphere, all of which crowd toward the centre, the stronger and heavier segments taking precedence and squeezing the weaker and lighter ones between them."[6]

These are the mature convictions of two eminent geologists. Any doubt that arises from this statement, comes from the lack of clearness as to the mechanism by which the continental structures have been developed.

With acceptance of the principle of isostasy, new concepts were bound to arise. The following summary made by Leith[7] gives a brief outline of some of the current views regarding

[6] Chamberlin and Salisbury, Geology, Vol. I, p. 545.

[7] Leith, C. K., Structural Geology, 1923, p. 316.

the depth and thickness of the zone in which isostatic adjustment is effected:

> "Gilbert conceived 'a relatively mobile layer separating a less mobile layer above from a nearly immobile nucleus,' the mobile layer agreeing in depth with the depth of isostatic compensation.
>
> "Barrell called this weak zone the *asthenosphere* and placed its provisional boundaries at depths of 75 and 450 miles from the surface. This he conceived to underlie the depth of isostatic compensation.
>
> "Hayford assumed concentration of movement within the lower part of the zone of isostatic compensation, that is, within 75 miles of the surface. Bowie and others place it below the depth of compensation.
>
> "Willis concludes that there is a zone of adjustment below 40 miles and extending to the base of the asthenosphere, and that the adjustments necessary to isostatic undertow take place mainly between 45 and 100 miles of the surface."

In a recent paper[8] reasons were advanced for concluding that isostatic adjustment may be effected through a zone of relatively limited vertical thickness, the dimensions and depth of which are determined by environmental conditions. Temperature-, pressure- and presumed compositional-zoning into concentric earth shells is entirely opposed to the conception of isostatic adjustment taking place in a thick zone, such as the asthenosphere. A thick zone must necessarily have sufficient variations in the zoning factors mentioned, to necessitate that one part of the zone will yield more readily to differential pressure than another. In this yielding part, mechanical heat from subsidence will be so concentrated that the limitation of the zone's thickness is reasonably assured. Now, with the abundant source of heat available from subsidence, as made plain in the accompanying table, the reason why the zone of adjustment is limited in thickness becomes all the more apparent. Temperature becomes the prime factor.

The conception of sheet-flow in the zone of isostatic adjustment is strengthened from the consideration that with it, there is a logical explanation of the formation and intrusion of magmas. The magmas, in turn, are impelled by great force and are agents for the deformation of the earth's crust.

Conditions of temperature, pressure and composition largely determine, in the case of each subsidence, at what depth the sheet-zone will give way. After the first giving way, the factor of temperature, owing to the abundant supply of heat from the subsidence, will eclipse all other factors. The writer formerly[9] suggested depths up to 50 miles. This estimate was made from a consideration of geological and geophysical evidence, such as that pertaining to the probable depths of continental sial. Since the question of the production of magma is raised in this paper, the best conclusion to draw is that the lower limit of sheet flow is in or close to the primary earth-shell which has the composition of peridotite. It is commonly at depths within basaltic layers of the sub-crust and at levels corresponding to the depths of the continental sial. But the zone merges to the surface at all angles, the angles being determined by the local structures of the outer crust.

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[8] DeLury, J. S., op. cit.

There must be a lateral escape of material at depth to permit subsidence to continue. The heat available from subsidence is concentrated where there is most motion and friction. The mechanism is likened to that of ice-sheets[10] in which a relatively warm bottom sheet is moving outward and escaping to relieve the subsidence of the overlying carapace of ice. If enough heat is concentrated in the sheet-zone of flow and the viscosity of the sheet tends to be lessened thereby, there will be a compensating tendency to absorb wall-rock and so to lower temperature and increase viscosity. The velocity of the sheet-flow, its material, its thickness and viscosity are determined by the environment.

The sheet-flow is the source of magma. It takes the place of the hypothetical magma-reservoir or magma-chamber. Magma issuing into the crust or to the surface, is thrust with much of the energy of the subsidence behind it. Intrusive bodies are regarded as occupying secondary magma-chambers, secondary in the sense that the magmas have not formed locally. Sheet-flows and magmatic injections are conceived to be the directing agents of deformation in the earth's crust.

The term "viscosity" is used rather loosely by the writer, but the meaning is obvious. It is impossible to describe the exact condition of matter in the sheet-flow and in the successive stages until injected as intrusives. With the rise of magma in the crust, there is a more ready release and less friction for generating heat, but greater mobility from decrease of pressure. It is obvious that the conception favors assimilation rather than differentiation as an igneous process.

[9] DeLury, J. S., op. cit.

[10] DeLury, J. S., Experiments with Model Glaciers, Jour. Geol., 34, 266-274, 1926.

BEARING ON ISOSTASY.

An extreme view is sometimes advanced that irregularities on the surface of the lithosphere are to be explained by differences in density caused by differential heating or cooling or by molecular and atomic changes, and that vertical movements are the important ones in crustal deformation. On the other hand, most agree that the continents are relatively high because they are underlain by concentrations of the lighter material of the outer earth-shell. Moreover, there is an increasing demand on geological theory for conditions and a mechanism in the crust, which will permit an explanation of the great horizontal movements which have taken place. Geological authorities claim that there was a movement along Alpine thrusts of hundreds of miles and that in the Himalayas a horizontal shifting of 1,800 miles must be accounted for.

Most isostasists consider that adjustment of balance is effected through a sub-crustal zone. The idea of an under-current and even of an undertow has been suggested[11] by several geologists and isostasists. The undertow has been regarded by some as a possible factor in mountain-building.

The conception that most of the deformation of the outer crust has been brought about through the mechanism of a sheet-flow, the energy for which comes from subsidence, does not conform with an earth's crust which is supposed to be, and to have been, in a condition of isostatic balance. In this difficulty the isostasist must face the facts from earth history. Subsidences and elevations of large portions of the earth's surface have been continuous throughout geological time and especially marked in certain critical periods. It would seem that earth distortion must be appealed to, and it must be a distortion which calls for greater forces than those which are effecting the isostatic balance of to-day. Apparently some factors must still be weighed. The time factors of distortion and isostatic adjustment are not known. It is not known how variable the strength of the earth's crust may be. Isostatic balance may be effected in an outer zone following a deeper distortion in the earth.

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[11] Dutton, C. E., On Some of the Greater Problems of Physical Geology, Bull. Phil. Soc. Wash., 11, 113-23, 1889. (Reprinted in Physics of the Earth's Crust, II, No. 78, Bull. Nat. Res. Coun. Wash., 1931.)
Hayford, J. F., The Relations of Isostasy to Geology, Geophysics and Geology, Science, N. S., 33, 199-208, 1911.
Spurr, J. E., The Ore Magmas, p. 484.
Brouwer, H. A., The Horizontal Movement of Geanticlines and the Fractures near their Surface, Jour. of Geol., 29, 560-77, 1921.

It is emphasized, however, that the evidence for the great subsidences of earth history is convincing enough to demand that isostatic and other conceptions must conform to it.

> "The fact that the great volcanic chains are situated on those belts along which movement and disturbance of the crust have taken place is significant . . . . . As will be explained more clearly later, the earth's crust is divided into great blocks, or segments, and these have in times past moved up or down with respect to one another. It is noticeable in many places that where one of these great blocks, measuring hundreds or thousands of square miles in area, has sunk, this subsidence has been attended by uprise of magma, outflows of lava, and commonly by volcanic action. . . . . . The mechanism of ascension of the magma in this way is likened to the action of a hydraulic press.
>
> "The old idea that the earth has a hot, liquid interior and that the downward pressure of the cold and solid crust collapsing on the shrinking nucleus forces this liquid out and thus gives rise to volcanoes has been completely disproved by a number of considerations and is no longer held. The independent eruptions of adjacent volcanoes in the same group, and the fact that the lava column in Mauna Loa stands 10,000 feet higher than in Kilauea, only 20 miles away, are disproofs of this view, and others will be mentioned later."[12]

The present writer agrees entirely with the authors of this quotation. He would add that the subsidence itself may form the magma and an appeal to a liquid interior is unnecessary to meet the facts laid down in their first paragraph. Students of volcanoes are still disturbed for an explanation of the relations of the Hawaiian volcanoes, as described in the last quotation. Such relations are predictable from the hypothesis of sheet-flow as the source of magmas. They would be expected in the later stages of a fissure eruption, and, on the other hand, are anomalous with the conception of a magmatic reservoir.

APPLICATIONS AND IMPLICATIONS.

Great subsidences are indicated by geological history. The probable cause is earth-distortion. Subsidence leads to sheet-flow, which is the source of magmas. The migration of the sheet-flow and the forceful intrusion of magmas are regarded as being the chief agencies in producing crustal deformation.

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[12] Pirsson and Schuchert, Textbook of Geology, I, 266, 1929.

An inference from the hypothesis is that magmatic differentiation, in its narrower meaning, takes place only after the emplacement of the magma. Assimilation, which is considered by many petrologists[13] to be a minor factor in producing diverse rock types, assumes new importance. Assimilation is continuous from the initiation of flow until the magma is finally solidified. Great quantities of surplus heat are available. The possibilities for the production of diverse rock types are greatly widened.

The deeper the crust has been exposed by erosion, the more it discloses the importance of igneous intrusion and the force of intrusion. The deeper the erosion in the pre-Cambrian Shield of Canada, the more relative importance the igneous rocks assume. The Shield areas are ones which should be examined for conditions that obtain in the sub-crust, and for the key to the forces which disturb the upper crust. The key lies in the preponderant intrusives which have deformed the invaded rocks. Could the continent of Asia be stripped of its surface rocks and so exposed at a depth of a few miles, it might be expected to show a surface comparable in rocks and structures to that of the Shield areas.

There is a commonly expressed feeling among geologists that conditions found in the Shield areas, notably in the pre-Cambrian Shield of Canada, offend the principle of uniformitarianism as it pertains to geological history.

> "The North American Laurentian granites and orthogneisses always cut sediments or other supra-crustal rocks whose degree of deformation constitutes a now famous major difficulty in structural and historical geology."[14]

The present writer suggests that there is ground for the opinion that the Shield areas show exceptional conditions only in so far as they are exceptionally exposed. They would seem to be the areas in which search would be made for the picture of conditions in the continent-wide lower crusts. What is under the younger plateaus?

With the use of the table containing liquefaction equivalents of subsidence, it would be possible to obtain an approximation of the quantity of magma made available by any measurable subsidence. In a broad way it would appear possible that the total of the subsidences indicated by geological history might bring about the production of magma in a quantity of the order of magnitude demanded by igneous geology. There may be a zone in the earth, not many miles below the surface, where the accumulation of heat from crustal adjustments eclipses that derived from the interior of the earth. The sheet-zone of flow and its associated intrusives may determine the positions of the outer isogeotherms more potently and directly than does the earth's internal heat.

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[13] Iddings, J. P., Igneous Rocks, Vol. I, p. 282; Bowen, N. L., The Evolution of Igneous Rocks, p. 184.

[14] Daly, R. A., Igneous Rocks, p. 92, 1914.

By invoking the aid of *auto-traction,* as suggested by the analogy to the mechanism of ice-sheets, the sheet-flow, by dragging the outer crust with it, may conceivably fold mountains and supply, later on, the batholithic intrusion beneath. In a recent paper, Reid, after a brief discussion of the history of mountain ranges, concludes:

> "Criteria such as the foregoing, and others based on faulting, show without question that all the mountain ranges, sufficiently well known to be used as tests, have been elevated long after the folding; and, therefore, that their present elevation is due to vertical forces and not to horizontal compression."[15]

In view of the fact that study of mountain systems shows that the history of each involves long periods of geological time, the present writer's interpretation appears to be in keeping with Reid's conclusion.

With the conception of sheet-flow, it is possible to offer an explanation of the arcuate forms which are so prevalent in earth structures and external features, and which suggest differential flow. By invoking the aid of auto-traction, again, there is the possibility for the interpretation of the great thrust-faults, which involve horizontal displacements of hundreds of miles. The same assumptions permit a conception of the formation of rift-valleys and perhaps of ocean deeps. The concentration into the continental masses of sial which may have been originally evenly distributed, and the fragmentation of continents may not present unsolvable difficulties.

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[15] Reid, H. F., Influence of Isostasy on Geological Thought, p. 119, Chap. VIII, Physics of the Earth II, Nat. Res. Counc. Washington, No. 78, 1931.

DISCUSSION AND COMMUNICATIONS.

ESKERS AND THE LAST ICE SHEET IN DENMARK.

In a recent paper[1] of interest to geologists concerned with Pleistocene glaciation, S. A. Andersen of the University of Copenhagen, offers an explanation of some of the late-glacial deposits of Denmark. He conceives of the last ice sheet, which moved across Denmark from southeast to northwest, as having had an active inner mass surrounded by a stagnant periphery, the stagnant zone widening year by year at the expense of the inner active ice.

He believes that tunnels were melted out of the base of the moving ice by escaping streams which flowed under pressure as long as ice movement kept fissures and other openings closed up. The water under pressure had power enough to erode valleys two or three miles wide and 150 feet deep in the underlying ground moraine. This extraordinary width is explained by the assumption of a volume of meltwater great enough to buoy the ice up, flowing and eroding beneath it. As the zone of stagnant ice migrated inward, however, progressively affecting the tunnels headward from their mouths, openings in the ice could no longer be closed up, and water easily leaked away from the tunnels, lost pressure, and was forced to deposit its load where formerly it could not only carry debris with ease but also erode its bed. Stratified sand and gravel were laid down, usually in open-topped troughs between overhanging walls of stagnant ice. When the ice wasted away these deposits remained as eskers occupying the channels earlier eroded by the same streams while the ice was still active. Thus each valley contains an esker virtually as long as the valley itself.

According to Andersen the eskers in eastern Denmark trend roughly east-west. Each consists, in ground plan, of a series of bows or arcs convex northward and about two miles long. At the nodes, where successive bows meet, the esker is low or discontinuous, and is composed of fine sand, silt, and clay. At the centers of the arcs (the "esker centers" of de Geer) the esker is higher and is built chiefly of gravel and boulders. These "centers" are regarded as representing abundant coarse deposits made during summer seasons when melting was rapid, whereas the much finer material at the nodes is assigned to winter deposition when melting was at a minimum.

In each tunnel, the point where deposition first began to take place is regarded as having migrated backward through the ice coincidently with the retreating line of demarkation between active and stagnant ice. According to this view the "centers" represent summer positions of this point, and the nodes winter positions. The author concludes that each bow therefore apparently represents deposits made during a single year. He finds that parallel eskers have approximately the same number of bows, and argues that lines connecting corresponding bows through several eskers represent successive retreating positions of the line separating active ice from stagnant ice.

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[1] The Waning of the last continental glacier in Denmark as Illustrated by Varved Clay and Eskers, Journal of Geology, Vol. 39, pp. 609-624, 1931.

Andersen suggests that the formation of the bows or arcs may be due to deformation of the containing tunnels each summer as renewed movement, oblique to the tunnel axes, pressed active ice against the stagnant ice with which it was in contact. In support of this explanation he points out that the fine material at the nodes is undisturbed, whereas the coarse material near the "centers" commonly has an anticlinal core, with dips locally approaching the vertical, surrounded by beds whose dips decrease outward.

The sequence of events outlined in the foregoing résumé represents a new combination of ideas, a reconciliation of the retreating-ice-front theory of esker genesis proposed[2] and long maintained by de Geer and seconded by Trowbridge,[3] with the manifest evidence of stagnant ice in eastern Denmark. Although Andersen's paper cites evidence that proves the former presence of stagnant ice, he offers no support for his conception of a widening stagnant peripheral zone, other than the statements summarized above. Yet when the points made are analyzed, they seem to afford less support than could be wished. Water under pressure in an ice tunnel might be able to excavate a narrow trough; few would admit that it could excavate a valley two to three miles wide. To circumvent this difficulty, Andersen buoys up the entire segment of active ice lying above the subglacial stream, and thus allows the stream to erode the subglacial floor. Granted flowing water under hydrostatic head, and with a depth nearly as great as the thickness of the ice itself—a difficult situation to conceive of—the resulting flotation of the overlying ice would inevitably result in its cracking and crevassing, thereby causing the water to leak away, lose its pressure, and stop the process of valley excavation. With its hydrostatic head destroyed, water finding its way around and between the fragments of the disrupted ice mass let down into the valley that was excavated while the ice floated, would deposit detritus in the available spaces. After melting, this deposit should be a reticulated network of glaciofluvial material; not the single narrow continuous esker, occupying a fraction of the width of the valley, that is actually present.

No consideration is given to the age of the broad valleys which are assigned so bizarre an origin. The simple statement is made that the valleys were excavated by streams of meltwater underneath the ice, but no facts are cited to prove that they were not cut partly or entirely prior to the last glaciation, an explanation entertained by German investigators for the very similar *Urstromtäler* of the north German plain.

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[2] de Geer, Gerhard, Om Rullstensåsarnas Bildningssätt, Geol. För. Förh., Stockholm, Vol. 19, pp. 366-388, 1897.

[3] Trowbridge, A. C., The Formation of Eskers, Iowa Acad. Sci., Proc., Vol. 21, pp. 211-218, 1914.

If the eskers were built successively from west to east as stated by Andersen, the finer deposits laid down at one time should overlap and lie against the sides of coarse deposits laid down at an earlier time. No mention is made of this point, although it is a necessary consequence of the hypothesis advanced, and we are left without information on it.

The statement is made (p. 623) that one of the valleys contains in addition to its esker, one or more constructional ice-contact terraces "closely connected with the esker deposits." No further discussion of the terraces is offered, although obviously no explanation of the eskers is complete if it does not also include and account for the terraces connected with them.

It is unfortunate that in the treatment of these interesting features only one hypothesis of their origin is entertained. This appears to have resulted in faulty deductions from the hypothesis adopted, as well as in failure to explain all of the facts at hand. The presentation of a problem dealing with a foreign area by a foreign geologist, in the English language and in an American publication, is an unusual event appreciated by American investigators; it is to be hoped that the more detailed publication promised by this author[4] will discuss the pros and cons of alternative hypotheses and will offer additional data on this interesting region.

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[4] *Op. cit.*, p. 609, footnote.

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics.

Recent Advances in Physical Chemistry; by Samuel Glasstone. Pp. vi, 465; 32 illustrations. Philadelphia, 1931 (P. Blakiston's Son & Co., price $3.50).—This book surveys the advances in physical chemistry of the last decade under the following headings: The electronic theory of valency, the parachor (Sugden), dipole moments, molecular spectra, homogeneous gas reactions, photochemical reactions, the properties of surfaces, heterogeneous catalysis, solubility, strong electrolytes, and acid-base catalysis. The author has used a number of excellent monographs as a source of information in preparing his material and then supplemented this with some of the more recent developments. In one or two chapters it seems that the monographs have been followed too closely, a condensation of subject matter being the single achievement. The chapters on dipole moments and molecular spectra are well written and the latter, in particular, should be of interest to those physical chemists not acquainted with the subject. The chapter on strong electrolytes is merely an introduction to some of the concepts used in the succeeding chapter on acid-base catalysis. The simple theory of heterogeneous catalysis is presented, but that is not enough, for the exceptions to the simple theory have prevented any two independent investigators from arriving at nearly the same result and interpretation for any given heterogeneous reaction. In about a space of fifty pages it may be possible only to present the simple theory; nevertheless, the imperfections and misapplications of the theory should have been pointed out.

This book should be of interest to organic chemists who are interested in the results of the recent advances in physical chemistry which they may apply to their own work and is to be recommended to students for advanced reading. Physical chemists will find certain chapters well worth reading depending on the subjects with which they are not well acquainted. The book is not expensive.

J. K. DIXON.

Chemical Analysis of Inorganic Substances; with Qualitative Analysis; by Olin Freeman Tower. Sixth revised edition. Pp. xv, 92. Philadelphia, 1932 (P. Blakiston's Son and Co., $1.50).—This text, the sixth edition of a book originally published in 1909, is designed primarily for a half-year course, and contains the usual procedures for the analysis of both the basic and acidic ions. An introduction serves to set forth the major principles involved in the separations, and explanatory notes are added to the laboratory directions for each particular group. In general, no reactions involved in the analysis are given. Instead, the student is referred to the proper pages in Holmes' "Chemistry" and McPherson and Henderson's "General Chemistry," either of which may be used in conjunction with the qualitative manual.

JOHN E. VANCE.

The Effect of Temperature in the Magnetic Treatment of Steel.—In a recent number of this Journal (Vol. 22, 281, 1931) an abstract of an article by E. G. HERBERT was published on the hardening of metals by rotating magnetic fields. In this it appeared that the effect produced in steel is not a simple hardening as was at first supposed, but that it gave rise to a sequence of hardness changes of a complicated but apparently periodic character generally extending over many hours. The author has now extended his investigations in seeking to find the effect of varying the temperature at which the magnetic treatment is applied.

When the hardness was plotted as ordinate and the time as abscissa the characteristic sequences of the curves were found at room temperature to be a fall, rise, fall, rise; at 100°, a fall, rise, fall; while at 200° C. it was a fall, fall, rise, fall.

Further experiments were made with a view to ascertaining the most favorable temperature at which to apply the magnetic treatment to a high-speed steel. The sequence of changes produced by magnetic treatment at 60°, 80° and 100° were found to be a fall, rise, fall, the final hardness being greatest in the specimen treated at 100° C. At intermediate temperatures of 160° and 200° C. the sequence of hardness changes was found to be a rise, rise, fall. The graphs for treatment at 240°, 270°, 320° and 370° C. show a complete reversal of the sequence found at the lower temperatures, being now a rise, fall, rise, the fall at the higher temperatures being very marked.

It was inferred from the above that the best results were obtained by treating the plain carbon steels at room temperature, ordinary high-speed steels at 200° C., and cobalt high-speed steel at 150° C.

The question of the most effective duration of magnetic treatment was also investigated. It appeared that one turn or 100 turns gave approximately the same final hardness, but that ten turns gave a decided fall followed by a rise but to a distinctly lower maximum. The author concludes that the maximum hardening may be produced by a single turn in the magnetic field at a suitable temperature followed by a period of aging.

The speed of rotation appeared to have little influence upon the result. Experiments were made with periods as slow as one cycle in 20 sec. and as fast as 500,000 cycles per sec. but it was not possible to attribute any effect to the influence of different speeds.

Further confirmation was found for the view that the cloudburst bombardment and the rotating magnetic field are not merely alternative methods for increasing the hardness of steel but that both processes may be applied to the same specimen, the effect of the second process being superimposed upon the first. As a consequence, the two processes may now be used in combination to produce a degree of hardness both at cold and at high temperatures, such as has never been attained before in steel.

Having established the fact that the effect of a rotating magnetic field is to set up periodic fluctuations in the hardness of metals, the author is led to speculate upon the cause of the phenomenon. The picture which presents itself to mind is a mass of spinning atoms which undergo a slow precessional motion under the influence of the field. The author has tried certain experiments in which he thought he observed an artificially produced change of spin and an accompanying change in the precession but these results are of very doubtful acceptability.

One important possibility however emerged from these investigations, namely, that of stabilizing the metal at a selected phase in the fluctuations set up magnetically or otherwise. It is illustrated by the stabilizing of steel wire in a condition characterized by greatly increased ductility, but with undiminished tensile strength. *Metallurgia,* May and June, 1931. F. E. B.

The Waidner-Burgess Standard of Light.—Since physical light by its definition involves both physiological and psychological reactions, it is not possible to derive a unit of light from purely physical elements. It would perhaps seem as though an arbitrary unit of luminous intensity might be defined in terms of the radiation of a specified amount of energy of a definite spectral distribution but there is at present no means available for determining radiant energy with an accuracy approaching that desired in modern photometry. Consequently we are obliged to fall back upon a specification of the source which produces the light.

The first of these standards was the sperm candle adopted in 1860. Then followed the Pentane lamp in 1877, and the Heffner lamp in 1884. No one of these flame standards is satisfactory because the lamps are not accurately reproducible and because their light output is dependent upon atmospheric conditions which cannot be controlled with sufficient accuracy. Violle in 1879 proposed to use the luminous surface of platinum at its freezing point as a standard but this although it seemed to give promise of a satisfactory reproducible standard proved in actual practice to be even less reproducible than the flame standards.

No one fundamental reference standard reproducible accurately enough for the purpose of modern photometry has been available up to the present. In 1909 the then existing units of candle power of Great Britain, France, and the United States were brought into agreement by the definition of the international candle and this unit has since been maintained by means of carbon filament lamps deposited in the various laboratories.

In 1908 Waidner and Burgess suggested as a standard of light a black body immersed in a bath of freezing platinum. This proposal has now been experimentally realized by Messrs. Wensel, Roeser and others. They have examined the light emitted by a hollow enclosure of thorium oxide immersed in freezing platinum and find it reproducible within the limits detectable by visual photometry. The brightness of this source according to their determination is 85.84 ± .09 candles per sq. cm. *Bureau of Standards Research Paper No. 325.* F. E. B.

Has Science discovered God? A Symposium edited by EDWARD H. COTTON. Pp. lviii, 308; frontispiece and 16 portraits. New York, 1931 (Thomas Y. Crowell Company, $3.50).—The answer to the question in the title of this book is No. No one can furnish a scientific proof of the existence or nature of God. Science can not deal with this mystery; it is a matter of faith alone.

It will perhaps surprise the reader of this book to learn how many of the best scientific minds are convinced that we are not living in a mechanistic dispensation but in a universe of order and design and of beneficent purpose.

In it the editor has collected sixteen essays by well-known men such as Millikan, Eddington, Conklin, Jeans, Einstein, and Sir J. Arthur Thomson. In these the authors have surveyed the field of religion and science and reached the conclusion that present-day research sees design in the universe and because there is design there must be an entity of some sort making the design. The import of the book is well summed up in these words of E. G. Conklin: "No one can furnish scientific proof of the existence, or nature, of God but atheism leads to fatalism and despair while theism leads to faith, hope, and love. 'By their fruits ye shall know them.' Science cannot solve the great mystery of our existence—why we are, whither we are bound, what it all means. Faith alone assures us that there is a definite purpose in all experience. This knowledge makes life worth living and service a privilege." F. E. B.

Signals from the Stars; by GEORGE ELLERY HALE. Pp. xx, 138, frontispiece and 56 figs. New York, 1931 (Charles Scribner's Sons, $2.00).—This book contains four essays which have appeared in popular magazines in somewhat different form. It takes its title from those clues to the constitution and structure of the stars which arise from the rhythmic rise and fall of the light of faint variable stars in remote spiral nebulae and the outbursts on the face of the sun which may forecast a brilliant aurora or affect radio transmission. The first essay glances rapidly over the history of astronomical instruments, reviews present achievements with 60 and 100-inch telescopes, and speculates hopefully on the possibility of a 200-inch mirror. The second chapter describes the way photographs of the sun are made in calcium or in hydrogen light, and what they reveal as to the solar atmosphere.

The third chapter continues the discussion of solar prominences and eruptions and traces an evident connection between such outbursts and brilliant auroras. The last chapter considers the general project of a 200-inch telescope, the construction of the mirror, a tentative design for the equatorial mounting, the principles which govern the selection of the most favorable site, the general plan of the Astrophysical Laboratory of the California Institute and the accessory optical and machine shops.

This book will take its place beside the author's *Beyond the Milky Way,* and *The Depths of the Universe.* F. E. B.

James Clerk Maxwell; by SIR J. J. THOMSON, MAX PLANCK and others. Pp. 146, frontispiece and one other portrait. Cambridge and New York, 1931 (The Macmillan Company, $2.50).—This is a commemoration volume published in celebration of the centenary of Maxwell's birth. J. J. Thomson has given the longest essay in which he reviews the life of Maxwell and his principal contributions to science, namely, his prize essay on Saturn's rings, the Theory of Color, the Dynamics of the Electromagnetic Field, the Viscosity of Gases, and the Electromagnetic Theory of Light. Planck writes on Maxwell's influence in Germany, Einstein on Maxwell and Physical Reality, while Larmor, Jeans, Garnett, Fleming, Lodge, Glazebrook and Lamb all contribute short essays explaining Maxwell's methods or recalling memories and experiences of the writers with this famous physicist. F. E. B.

Meteorology; by DONALD S. PISTON. Pp. viii, 187, 94 figs. Philadelphia, 1931 (P. Blakiston's Son and Co., $2.50).—Meteorology has always been to us the unpredictable science, for who, given a mass of air and water vapor, could possibly foresee the production of rain and snow and wind and the great variety of weather which must somehow be accounted for on the assumption of these simple elements?

Although we have many treatises on the weather the above-named work is one of the rare textbooks for the ordinary high school student. As few such students have any preparation in physics the author has devoted a portion of the book to the explanation of the physical principles which are essential to the study of meteorology. He occasionally seems to go beyond the depth of his class, as on pp. 20 and 124, but on the whole he keeps to a straightforward discussion of the atmosphere and its meteors. The book will furnish the general reader a very satisfying account of all the weather phenomena in which he is likely to be interested and particularly of the subject of weather forecasting. F. E. B.

GEOLOGY AND MINERALOGY.

Principles of Structural Geology; by C. M. NEVIN. Pp. 295; 128 figs. New York, 1931 (John Wiley & Sons, $3.50).—The purpose of this new textbook on structural geology is definitely stated in the preface. It is written for beginning students, "as simply as possible." "Matters now in dispute among geologists are not avoided simply because they are unsettled." "An effort has been made to stimulate an ability to reason, and the subject is therefore not presented in a dogmatic manner."

The desire to present this intricate subject as "simply as possible" arises as the usual concession to the average undergraduate who is inadequately prepared in mathematics and mechanics, and who is made to think his schedule too full to enable him to lay the needed foundation. There is danger in such willingness to accommodate. By stooping too far, the teacher will keep the student from realizing the need of acquiring a sound basis of physical knowledge before he can hope to reason correctly along lines of physical geology.

The aim to avoid all dogmatism, on the other hand, is evidence of a liberating trend in higher education. It permeates the book in salutary fashion.

The scope of the book covers both individual structures and their synthesis into the larger aspects of crustal deformation. Eight chapters are devoted to the former, three to the latter. Among the former, brief space is given to subjects developed especially by studies in oil fields. These include the effect of regional dip on flexures; thickening and thinning of sediments on flexures; compaction of sediments; value of aerial maps, etc. In the last three chapters a few facts and speculations concerning the earth as a whole are presented. Over ten pages are given to isostasy. Shape, distribution, permanency of continents and the pros and cons of continental drifting are discussed, in addition to the traditional problems of "mountain making."

Taken as a whole, the book serves to open up the general field of facts and interpretations of structural geology to an elementary mind in a way that makes it conscious of the uncertainties in existing information, of the dangers in hasty conclusions, and the diversity of present-day opinions.

The text is kept "simple" not only in expression but by the exclusion of most concepts and terms which go beyond a very elementary level. This is true of matters geological as well as mechanical. ("Evidently the Alps is no territory for the beginning student of structural geology, and about all one can hope to do is to grasp the fact and magnitude of the low-angle thrusts so well developed there."—pp. 113-114.) This is carried so far that some chapters, for instance those on solid flow and on theories of failure, are quite ineffective. In general, the realities seen in the field are not set forth clearly, but are presented intertwined with ideas about them to such an extent that in many cases the beginner must be left without a clear picture. Moreover, the interpretations of deformations in terms of stress tend to be presented in such a way that they cause confusion. In some cases the interpretations themselves are open to question.

Much confusion arises, for instance, from the failure to distinguish between principal axes of stress at a given point within the body, the pair of forces applied externally to the body which produce the stresses, and the direction of the unbalanced or "active" force. All are called "stress" by the author. We read, for instance, that in the case of rotational strain "although the axis of greatest total shortening (least strain) again bisects the angle between maximum shear planes, the axis of maximum stress does not." (p. 22). On page 88, we read of shear planes dipping "toward the direction of stress" and others that dip "away from the direction of stress."

Dip and strike joints are interpreted as tension joints. About their origin we read: "Thus in folded regions there may be tensile stresses in two directions at right angles to each other, so making possible the formation of a system of joints" (p. 114). No mention is made at this point of the strain ellipsoid which is given much space otherwise. (It appears in six diagrams and is directly implied in several others.)

In the "section illustrating cross-bending or flexure" (fig. 8, p. 18) the "neutral axis" is drawn close to the concave side, but nothing is said about inhomogeneities which alone would justify such a condition.

On page 86 we read, for instance: "Since faults are limited to those fractures where the major displacement has occurred parallel to the surface of parting, they can be produced only by shearing." Here, as throughout the book, the author fails to take into consideration the possibility that the external forces which produce a fracture were not the same as those which cause displacement of the severed rock masses.

Unfortunately, inaccuracies and errors occur in connection with other matters, as a few quotations may show:

Dip and strike "are an integral part of flexures" (p. 36); Fig. 1 (Space lattice of a salt crystal) "illustrates the structural grouping of the atoms in a common sedimentary rock" (p. 2); "the atom itself is composed of still smaller particles, the electrons" (p. 2).

"The rigidity of the crust is 6.8×10^{11} cgs and the inner part of the sphere is 19.7×10^{11} cgs," (p. 226). (Since the author considers it necessary to tell the reader the meaning of 10^{-5} (p. 229), he should explain "cgs.")

Glass "possesses great viscosity but little if any rigidity" (p. 6). (Since tables of physical constants give the modulus of rigidity of glass, this use of the term requires explanation.) "If a glass is a super-cooled or very viscous liquid, then under conditions of stress it should react according to the laws for liquids" (p. 5). (As glass is widely spoken of as the building material of the future in competition with stone, this statement needs qualification.)

In figure 3, the familiar load-extension curve of a non-brittle material such as steel is given to illustrate "the deformation of cast iron, a relatively brittle material" p. 10).

On pages 222-223, the reader is told that "the precession of the equinoxes should cause a rhythmic displacement of the poles"; that "the supposition is that the inclination of the earth's axis (23°27'7") has been easily maintained since at least the beginning of readable geologic history."

The book is well printed in large type on thick glossy paper and is practically devoid of typographical errors.

WALTER H. BUCHER.

Catalogue of the Pontian Carnivora of Europe; by G. E. PILGRIM. Quarto. Pp. i-vi, 1-174, 30 text figs., 2 plates. London, 1931 (Published by the British Museum of Natural History, 15 shillings).—This excellent monograph is a companion volume to the "Catalogue of the Pontian Bovidae of Europe" issued in 1928 (this Journal, **16**, $5.50). The present work includes all of the species of Carnivora of Pontian (Upper Miocene or Lower Pliocene) age in Europe and is not restricted solely to those represented in the collections of the British Museum. Hence its value as a systematic guide to this particular fauna is increased.

The following families are described: Canidae, Ursidae, Procyonidae, Mustelidae, Viverridae, Hyaenidae, and Felidae. The classification is based upon that of Zittel (Grundzüge der Paläontologie, revised by Schlosser in 1923), and a diagnosis of every family, sub-family, genus, and species is given, embracing all of the latest information on these forms. New species described are: *Martes woodwardi, Enhydriodon (?) latipes,* and *Felis neas,* while *Sivaonyx* is erected as a new genus of the sub-family Lutrinae.

As the group of the Pontian Carnivora of Europe and North America has so very few, if any, forms that are exactly alike, Dr. Pilgrim's work will prove to be of inestimable value for comparative purposes to American paleontologists and will undoubtedly pave the way for a very much clearer understanding of the relationships between these diverse faunas.

Eight pages of references and ten of index complete this very valuable contribution to the knowledge of the Carnivora.

M. R. THORPE.

Etude Synthétique sur le Mésozoique Mexicain; by C. BURCKHARDT. Mém. Soc. Pal. Suisse, vols. 49-50, 280 pages, 18 plates, 65 text figures, 1930.—This highly interesting and most valuable synthetic study of the Mesozoic stratigraphy of all Mexico—which embraces about nine-tenths of the sedimentary deposits—brings together all that is known of the rocks belonging to this geologic era. For this extensive task no one was better fitted than the author, who has been at work on these deposits and their fossils for more than a quarter-century.

The Upper Triassic and Lower and Middle Jurassic have limited distribution, but with the Upper Jurassic began the greatest flood of Mexico, Central America, and Antillia, which attained its climax of spread in Middle Cretaceous time, when all of Mexico was covered east of the Sierra Madre Occidental. The Cretaceous is divided into three parts, according to the Mexican custom. With a thoroughness attained by no one before him, Burckhardt studies the formations and faunas, locally and in general, from the standpoint of facies, i.e., the nature of the seas and their depth, the bottom deposits, the reef characteristics, and the distance of the deposits from land. His bibliography cites 180 titles, the information from which is all checked into his personal knowledge of the strata and fossils.

The volume will long remain the classic on Mexican Mesozoic stratigraphy, and the author is to be highly congratulated on the completion of his great work, which has been of the greatest service to the reviewer. C. S.

Stream Sculpture on the Atlantic Slope; A Study in the Evolution of Appalachian Rivers; by DOUGLAS JOHNSON. Pp. xxii, 142, with 21 text figs. New York, 1931 (Columbia University Press, $3.25).—Not only all geomorphologists, but all those who are interested in the development of the Appalachians will find in this book material for serious study that compels interest and stimulates thought. The core of the discussion appeared recently in abstract in the Bulletin of the Geological Society of America,[1] and elsewhere as a complete statement,[2] but even if this later presentation did not contain a mass of well-marshaled and well-illustrated detail not given in the author's earlier publications, the argument it contains is so cogent and so well arranged that it would still reward a close reperusal.

The theory offered is that the transverse drainage of the northern Appalachian region was superposed from a coastal plain extending from 125 to 200 miles inland across the Appalachian ridges and resting on a peneplane older and higher than the highest surface now preserved on the ridges. Reasons are given for adopting a view set forth by earlier investigators, that the beveled surface of the crystallines underlying the Cretaceous coastal-plain deposits is older than the highest upland peneplane. Among others may be mentioned the scarcity of coastal-plain remnants inland from the Fall Zone, a fact that has long puzzled investigators proceeding on other basic assumptions. The belief is then stated that the beveled sub-coastal-plain surface (transecting Triassic and overlain by Cretaceous rocks) formerly extended far inland and is probably the one through which extensive superposition occurred.

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[1] Vol. 42, 196, 1931.

[2] Johnson, Douglas, A theory of Appalachian geomorphic evolution, Journ. Geol., 39, 497-508, 1931.

——— L'évolution du réseau fluvial dans la partie centrale des Appalaches, Annales de Géogr., 40, 639-654, 1931.

From the Potomac north to the Saco, the chief streams draining this region to the Atlantic flow southeast, are remarkably parallel, and are mainly not adjusted to the structure across which they flow. Furthermore, the water gaps and wind gaps of the northern Appalachian region are mostly aligned across successive ridges. These facts favor superposition rather than any other theory yet advanced to account for Appalachian drainage.

Other facts are, however, favorable to superposition specifically as derived by the author. One is the remarkable development of adjusted tributary drainage in the folded Appalachians, which favors derivation of the mains from a surface vertically high above the present summits. Another is the incompleteness of the evidence of former drainage lines preserved in wind gaps, a fact difficult to explain by superposition through the present upland surface, but easily derived through readjustments accomplished *before* the completion of the highest peneplane preserved on the ridges. Another is the presence on the crests of Appalachian ridges of faint slopes toward water gaps and wind gaps, suggesting superposition before rather than after the development of the surface beveling the ridges into which the gaps are cut. Finally, the stratigraphic evidence of the existing coastal-plain deposits is not unfavorable to the conception of their former great extension inland.

The several arguments are not brought out in the order given above, partly because the author has used the method, so often employed by Davis, of deducing the consequences of his hypothesis and confronting them with the facts. The subject lends itself well to this type of treatment, and as an example of scientific method it can be commended in the highest terms to students of geology. The method is perhaps best displayed in the chapter in which the consequences deduced from the theory of regional superposition are compared in detail with the drainage of Pennsylvania.

In a later chapter dealing with the present drainage, water gaps, and wind gaps of the Watchung region of New Jersey, the author presents an ingenious theory of superposition of a former *subse-*

quent stream at the base of a cuesta formed by Cretaceous coastal-plain deposits, and shows that it better explains the facts than does the theory of consequent streams superposed and later rearranged by capture, long ago advanced by Davis.

The entire discussion appears to be fair-minded and without prejudice. The author is very properly careful to point out that the thesis advocated does not require any particular number of erosion surfaces in the northern Appalachian region, nor any given correlation of the remnants now preserved on the uplands, other than the relatively greater age and inland extension of the sub-Cretaceous floor.

It is difficult to find matter to criticize in this study. Some may perhaps take exception to the structure offered in Figure 12, in which the presence of a supposedly Cretaceous coastal-plain remnant lying inland from the Fall Zone at a relatively low elevation is explained by Cretaceous or later thrust faulting. At most, the matter is not of critical importance to the author's thesis, because the age of the remnant has not been demonstrated to be positively Cretaceous. Explanation of the presence of the remnant therefore might perhaps have been approached through its uncertain age rather than through displacement, thereby avoiding the drastic assumption of Cretaceous or later thrust faulting for which the author offers no other justification. Again, the block diagrams in Figures 1 to 9 show the structure of the metamorphics of the eastern Appalachian region as inclined northwest instead of southeast. But these are very minor points indeed, and their fewness merely serves to emphasize the very high quality of the whole study. The work is unquestionably a major contribution to Appalachian geomorphology, and furthermore offers material for interesting speculation on the nature and sequence of the crustal movements that have occurred in this region since the folding of the Appalachian geosyncline. RICHARD FLINT.

Contributions in Geology, edited by CHESTER K. WENTWORTH. Washington University Studies, New Series Science and Technology. No. 5. Pp. 80. St. Louis, 1931.—Four papers based on work done in 1929-30 chiefly, are here included: (1) Pebble wear on the Jarvis Island beach by CHESTER K. WENTWORTH, pp. 11-37; 4 pls., 8 figs. (2) Pennsylvanian Ostracode from Hamilton Country, Kansas (Abstract) by DAVID M. DELO, pp. 40-51; 1 plate. (3) Minerals from Virginia Coastal Plain Terrace Formation by E. MITCHELL GUNNELL and WALLACE L. WILGUS, pp. 55-67; 1 fig., 1 table. (4) Rates of wear of common Minerals by ARTHUR B. COZZENS, pp. 71-80; 1 table.

The Celestite Locality near Clay Center, Ohio.—That interesting crystals of celestite have been obtained from Clay Center, Ohio, has been known for some time. The recent literature, however, does not seem to contain any statement in regard to this locality, hence the facts here given. For them the writer is indebted to Mr. W. J. Paquette of Toledo.

The crystals of celestite are found in pockets in the Niagara limestone, which are some 10 feet from the surface. The size of the pockets varies from 1 to 3 feet in height and width, and 10 to 12 feet in length. The common size of the crystals, which usually hang from the top, is ½ to 1 inch in width and ½ to 2 inches in length. Crystals 2 x 3 or 4 inches, however, are occasionally found. The crystals are tabular in habit parallel to the basal plane and elongated in the direction of the *b* axis. The macrodomes *l*(104) and *d*(102) are prominent; the brachydome *o*(011) is small. A pyramid, usually rounded, is evidently *s*(112). Two vicinal brachydomes, with a dull surface, are also observed. Fluorite in cubic crystals is often associated with the celestite. It varies in color from wine-yellow to dark brown, the latter crystals often in interesting groups. E. S. D.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

The Early Embryology of the Chick; by BRADLEY M. PATTEN. Third Edition. Pp. xiii, 228; 87 illustrations, including 280 figs. Philadelphia, 1929 (Blakiston's Son & Co., $2.50).—Wisely adhering to the belief that a beginner's textbook in embryology should be restricted to the essential thread of development, leaving comparative work until later, the author in this third edition of his well-known book, has still more closely approached the ideal. The sections on gametogenesis, maturation, and very early development, as well as those on relatively late phases, have been curtailed. Most of the book is devoted to a detailed account of the first four days of incubation, for it is then that the embryonic body is laid down and the organ systems established.

The illustrations are unusually clear and appropriate; their increased number compensates for the reduction of the text. A nineteen-page bibliography arranged according to stages and organ systems will be found quite comprehensive. S. C. B.

The Chr. Michelsen Institute of Science and Intellectual Freedom.—This Institute was established by a fund received from the estate of the Prime Minister Chr. Michelsen in accordance with his will of June 9, 1924. The total amount reached 5,500,000 kronen on November 30, 1929; of this sum 3,000,000 kr. forms the Main Fund, the remainder the Free Fund. The chief aim is to finance research workers of marked ability to work with the

Institute under liberal conditions. The special branches of science named are: (1) Philosophy of Religion, Psychology, or related branches; (2) Natural and Technical Science and Mathematics; (3) Religion.

Volume I of the *Beretninger* (Bergen, 1931) contains three papers as follows: (1) Th. Skolem on Mathematical Logic and Arithmetic; (2) H. U. Sverdrup: Thermal Properties of a Snow-covered Surface; (3) Kristian Schjelderup: Religious forms fundamental in Light and Psychology. The frontispiece gives an admirable portrait of the generous founder of the Institute.

Report of the Secretary of the Smithsonian Institution, DR. CHARLES G. ABBOT, for the year ending June 30, 1931. Pp. vii, 159. Washington, 1931. (20 cents.)—The following are notable points remarked upon in this report: The proposed extension of the Natural History Building of the National Museum for the plans of which $10,000 have been appropriated by Congress.—The income from about $50,000 (bequest of the late James Arthur) to be used for the study of the sun.—Important additions to the collections by successful expeditions, and from other sources.—A special matter of interest is the investigation of solar radiation, to which the Secretary has long devoted himself. Observations have been carried on by improved methods at the stations of Table Mt., California, and Mt. Brukkaros, Southwest Africa. The recorded results for 1920 to 1930 are now completed, with a probable error of less than 0.1 p.c. in the monthly mean values. Regular long-period variations have also been established. The work accomplished in the various departments of the Institution is presented in detail by the several Directors in the Appendixes 1 to 11 (pp. 22-159).

Annual Report of the Board of Regents of the Smithsonian Institution for the year ending 1930. Pp. xii, 650. With many excellent plates and figures.—This interesting volume contains the report of the Secretary for the year ending June 30, 1930 (pp. 1-146). Following this is the General Appendix (pp. 163-650) containing twenty-nine chapters on a wide range of subjects interesting to scientific men as well as to the intelligent reader. These subjects are well chosen from various sources, clearly presented, and profusely illustrated by excellent plates. For example, the Autogiro is described and its use explained by H. F. Pitcairn (pp. 265-273) with the help of 9 plates. The following contribution is on an allied subject, "Ten Years Gliding and Soaring in Germany" by Dr. Walter Georgii of Darmstadt (pp. 273-283, plates 1-16). "Weather and Glaciation" is discussed by Chester A. Reeds (pp. 295-326, 15 figs. and bibliography).

Index Generalis. I. Annuaire Général des Universités. Published under the direction of M. de Montessus de Ballore, "Edition Spes." 12 Mo. Pp. 2350. 17 rue Soufflot, Paris, 1932. (Price

225 francs.)—The previous edition of this remarkable compendium of valuable information in regard to the Universities, Academies, Libraries, etc., of the entire civilized world was issued in 1930 (this Journal, vol. 20, p. 157). The present volume embraces the same complete world survey as have the earlier issues dating from 1919. In brief, it contains an invaluable mine of information; essential to all who would be informed as to the intellectual activities of the world. How complete the volume is will be appreciated from the fact that it describes 1,100 Universities and Higher Schools, 315 Observatories, 3,000 Libraries, 250 Laboratories and 1,150 Learned Societies.

A second volume, containing an Index of the 75,000 persons named in Volume I now issued and the Geographic Tables, will follow with little delay.

Bureau of American Ethnology. (*Smithsonian Institution.*) Recent Bulletins are the following:

BULLETIN 98. *Tales of the Cochiti Indians;* by RUTH BENEDICT. Pp. x, 256. (40 cents.)—The Cochiti Indians inhabit a Pueblo of this name on the west bank of the Rio Grande, 27 miles southwest of Sante Fe. The interesting tales here recorded were obtained through interpreters by the author in 1924. To them have been added others by Professor Frank Boas recorded in text and given in close translation. The series begins with origin tales and stories of the Katcinas and societies; then follow groups of hero, novelistic, animal and European tales. The whole collection gives a vivid picture of the working of the minds and imaginations of these remarkable Indians, and hence of the life they tend to lead.

BULLETIN 103. *Source material for the Social and Ceremonial Life of the Choctaw Indians;* by JOHN B. SWANTON. Pp. 282; 1 fig., 5 pls. (60 cents.)—The Choctaws, known to other tribes as "Long Hairs," formerly occupied a territory in southeastern Mississippi. They were more numerous than the other tribes, the Creeks and Crikasaws, also early established in the Gulf region. The Choctaws remained at peace with the incoming American settlers but as the pressure of the latter increased, a treaty (1830) gave them a tract on the Red River in the present state of Oklahoma to which they emigrated in 1831-1833. This Bulletin describes in detail the two forms of the legend of the Choctaw origin. Following this are given in detail many facts of great interest as in regard to their social organization and the many customs as affecting their daily life. Especially interesting is the presentation of the subjects of medicine and religion.

Mikrokosmos. Volume 25. 1931-1932. No. 1. Franckh'sche Verlagshandlung. Stuttgart.—The twenty-fifth Jubilee year of this interesting monthly journal began with the issue of No. 1, October, 1931. It is devoted to microscopy, microbiology, microchemistry and microscopic technique, and is the organ of many microscopic societies in Germany and Austria. A wide range of subjects by distinguished authors are presented in the successive numbers. These are discussed as fully and clearly as each subject permits and are illustrated by many excellent and instructive figures. The quarterly subscription price for three numbers is 2.40 RM. The publishers offer to the subscribers to Mikrokosmos the gift of a book each year free of charge. Those thus far issued have been in the series: "Handbuch der mikroskopischen Technik" or, "Handbücher für die praktische naturwissenschaftliche Arbeit."

Abstracts of Scientific and Technical Publications from the Massachusetts Institute of Technology with Abstracts of Doctors' Theses Jan. 1 to June 30, 1931. Pp. 81. Cambridge, Mass., 1931.—The titles of these publications are grouped according to subject under eighteen heads, brief abstracts are given in many cases.

Fourteen Theses presented for Doctors' Degrees are noted: 3 in Chemical Engineering, 8 in Chemistry, 2 in Electrical Engineering, and 1 in Mathematics. The abstracts of these are given in full detail, in some cases running to three pages.

Third International Conference on Bituminous Coal.—The Carnegie Institute of Technology in Pittsburgh announces the publication of the papers and discussions presented at the Conference. These fill two volumes, 900 pages each and fully illustrated. Price per set $15.00, postage prepaid.

Scientia. Volume 51, No. 237.—The number of Scientia for January, 1932, commemorates the twenty-fifth anniversary of the foundation of this valuable monthly periodical. Since 1907 (this Journal, vol. 27, p. 100) the editorial board has been often expanded and the scope of the articles widened. Its value in the scientific world has thus increased year by year. The present number gives a complete summary of the numbers published from 1907 to 1931, with a list of the authors.

What Scientia offers to its readers will be shown by the titles of papers given in this number. These are as follows: Plato and the theory of science; Mathematics of forty centuries; Collisions with comets as causes of climate variations; The spectrum of Röntgen rays; Structure of organic molecules and the atomic theory; Some aspects of the problem of vitamins; The effects of change of language; Is science responsible for the world crisis?

Algèbre Figurée; Mathematical Ideographie; by JACOB LINZBACH. Pp. 200. Paris, 1931. (Jacob Linzbach, 28 r. Ducouedic.)—The author, on account of the great number of symbolic figures required, has published his ideas in manuscript form by a process called "autographie". The successive pamphlets form a journal of which each number containing eight pages appears once or twice a month. His symbols are indefinitely numerous, a man, a horse, a pen, a book, etc., with ideograms for, from, at, upon, between, across, within, etc., addition to the usual algebraic notation with letters, indices, and subscripts.

He makes up equations with these symbols; for instance, he writes x times a figure of a cat, plus a figure of a man equals zero. Now what does the cat do with the mouse if the result is zero? He replies that it indicates the cat does not wish the mouse, he is composed, he wishes something contrary to the mouse, and that is why he does nothing visible with the mouse. And so he goes on for page after page. We admit that he has shown great ingenuity in the interpretation of his symbols, but confess that we do not see that he has made any great contribution to mathematical ideas.

OBITUARY.

M. GUILLAUME BIGOURDAN, the celebrated French astronomer, died on February 29, in his eighty-first year. He was the head of the Toulouse Observatory from 1877 to 1897, and later the director of the Paris Observatory. In addition to his extensive work in astronomy, he was also active in establishing the International Time Bureau for Europe.

SIR GEORGE CLARIDGE DRUCE, curator of the Oxford University Herbarium, died on February 29, at the age of eighty-one years. He was the author of several botanical books and many original papers.

MR. GEORGE FORREST, the Scotch botanist and horticulturalist, died in West China on January 5, at the age of fifty-eight years. His original work was largely done in central Asia where he made very large collections on his eight expeditions.

MR. HUGH GIBB, chief preparator in the Peabody Museum of Natural History, New Haven, died on February 28, at the age of seventy-two years. A notice will appear later.

DR. WILLIAM PARKER HEADDEN, professor of chemistry and geology in the Colorado Agricultural College since 1893, and chemist of the Agricultural Experiment Station, died on February 5, at the age of eighty-one years.

DR. EDWARD ORTON, JR., State geologist of Ohio from 1890 to 1906, died on February 10, at the age of sixty-eight years.

DR. ROBERT WOOD WILLIAMSON, the English anthropologist, died on January 12, at the age of seventy-five years. He devoted much of his time to a study of the ethnology of Polynesia. His study of New Guinea and the Solomon Islands was particularly important.

Adv.—Crystals of Celestite from Clay Center, like those described on p. 383 of this number, also massive Celestite, may be purchased from Mr. Walter J. Paquette, 417 Fourth St., Toledo, Ohio.

PUBLICATIONS RECENTLY RECEIVED.

Chemical Embryology; by Joseph Needham. In three volumes. New York, 1931 (The Macmillan Company, $35 three vols. Cambridge University Press).

Smithsonian Institution. Bureau of American Ethnology. Bulletin 103. Source Material For The Social and Ceremonial Life of the Choctaw Indians; by John R. Swanton. (For sale by the Superintendent of Documents, Washington, D. C., Price 60 cents.)

Smithsonian Miscellaneous Collections. Volume 86. Smithsonian Meteorological Tables. (Based on Guyot's Meteorological and Physical Tables.) Fifth Revised Edition. Washington, 1931.

Monographs on Biochemistry. The Glycosides; by E. F. Armstrong, K. F. Armstrong. New York, 1931 (Longmans Green and Co., $4.25).

Das Kausalgesetz und Seine Grenzen von Philipp Frank. Vienna, 1932 (Julius Springer, 18.60 RM).

Field Museum of Natural History. Publication 305. Geological Series. Vol. VI, No. 1. The Auditory Region of The Toxodontia; by Bryan Patterson. Chicago, 1932.

Qualitative Chemical Analysis of Inorganic Substances with Explanatory Notes by Olin Freeman Tower. Sixth Edition, Revised. Philadelphia, 1932 (P. Blakiston's Son & Co., Inc., $1.50).

The Kinetics of Homogeneous Gas Reactions; by Louis S. Kassel. American Chemical Society Monograph Series. New York, 1932 (The Chemical Catalog Co., $6.50).

Physikalisches Handwörterbuch Herausgegeben von Arnold Berliner und Karl Scheel. Zweite Auflage. Berlin, 1932 (Julius Springer, 96 RM; bound, 99.60 RM).

Summary Report, 1930, Parts A, B, and C. Canada Department of Mines. Geological Survey, Ottawa, 1931. Memoir 165. Studies of Geophysical Methods 1928 and 1929. (Price 45 cents.)

The Theory of Groups and Quantum Mechanics by Hermann Weyl. Translated from the second (Revised German Edition; by H. P. Robertson). New York, 1932 (E. P. Dutton & Co., $6.00).

Manual of Meteorology. Volume IV. Meteorological Calculus: Pressure and Wind; by Sir Napier Shaw with the assistance of Elaine Austin. (New York, The Macmillan Co., $9.50. Cambridge: At the University Press.)

Papers from the Geological Department. Glasgow University. Volume XIV (Quarto Papers of 1927-1931). Glasgow, 1931 (Jackson, Wylie & Co.).

Les Principes Physiques de la Théorie des Quanta by W. Heisenberg, translated from the German by Mm. B. Champion and E. Hochard. Paris, 1932 (Gauthier-Villars et Cie, 40 fr.).

Report of the Librarian of Congress for the Fiscal Year ending June 30, 1931. Washington, 1931 (Government Printing Office).

Annual Progress Report of the Geological Survey for the Year 1930. Perth, Western Australia, 1931.

Carnegie Institution of Washington. News Service Bulletin, Vol. II, No. 26. Producing High-Speed Protons and Tracing Their Paths. Washington, 1932.

Ohio State University Studies. Engineering Series. Circular No. 24. Smoke and Its Prevention; by H. M. Faust. Bulletin No. 60. Strength of Concrete Block Pilasters Under Varied Eccentric Loading; by J. R. Shank and H. D. Foster. (Price 50 cents.) Columbus, 1931.

Les Etoiles dans Leurs Courses; by Sir James Jeans. Translated from the English by Sallin. Paris, 1932 (Hermann & Co., 35 fr.).

Petroleum in the United States and Possessions; by Ralph Arnold and William J. Kemnitzer. New York, 1931 (Harper & Brothers, $16.00).

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DOUGLAS JOHNSON.

ABSTRACT.

A theory of origin of piedmont desert rock planes, or pediments, through lateral corrasion by heavily laden streams is briefly outlined. Among the deduced consequences of this theory is the occurrence, near the mountain base, of forms closely resembling alluvial fans but developed by erosion on bedrock. Field investigation reveals the existence of such "rock fans," and several examples are described. It is concluded that the theory of lateral planation is sufficiently supported to deserve consideration among other working hypotheses of pediment origin, and suggestions are offered for further study of the problem.

INTRODUCTION.

In a recent issue of Science[1] the writer elaborated in some detail a theory of origin for desert erosion planes or rock pediments which seems to offer a possible explanation of these forms and their associated phenomena, and which therefore deserves a place among the working hypotheses being tested by students of desert forms. According to this theory there must normally exist in the drainage area of a desert range three concentric zones in each of which the dominant action of streams differs from that in the other two:—(1) An inner zone, *the zone of degradation*, corresponding closely to the mountainous highland, in which vertical down-cutting of streams reaches its maximum relative importance; (2) An intermediate zone, *the zone of lateral corrasion*, surrounding the mountain base, in which lateral cutting by streams attains its maximum relative importance. This is the zone of pediment formation. (3) An outer zone, *the zone of aggradation*, where upbuilding by deposition of alluvium has its maximum relative importance.

[1] Johnson, Douglas, Planes of Lateral Corrasion, Science, 73, 174-177, 1931.

The zone of lateral corrasion gradually encroaches upon the zone of degradation, due to the fact that the mountain front recedes under the sapping action of laterally corrading streams frequently deflected against the mountain base. In turn the zone of aggradation encroaches, for a time, upon the zone of lateral corrasion, the thickening alluvial deposits over-lapping the previously formed pediment. In the case of an originally circular mountain mass the end-result would be a far-spreading low rock cone blanketed in considerable part by overlapping alluvial deposits, were it not for the fact that the zone of lateral corrasion, in addition to shifting inward, is vertically lowered as debris from the shrinking and lowering mountain mass becomes progressively less abundant. The effect of this lowering is ultimately to cause an outward as well as an inward migration of the zone of pediment formation, and thus to make a low conical rock pediment, relatively free from alluvium, the ultimate type form of the arid landscape.[2] Since lateral cutting takes place *pari passu* with lateral shifting, unaccompanied by any considerable vertical incision of the streams, no thick "slice" of a pediment need ever be removed as its surface is lowered; although it is recognized that a marked change in physical conditions may in places cause deep trenching of the rock plane, followed by lateral planation at a notably lower horizon.

The foregoing "theory of lateral corrasion" assigns to planation by heavily laden streams not merely the local development attributed to it by Gilbert[3] in his classic work on the Henry Mountains, nor the subordinate importance apparently recognized by Kirk Bryan[4] in his excellent account of the Papago country, but the dominant rôle in producing plane erosion surfaces in arid regions.

In the present paper the term "desert" is employed in the loose sense so common in the literature, it being applied to arid regions generally, and with full recognition of the fact that forms most characteristic of arid regions are also found, under certain conditions, in regions having considerable rainfall. The term "pediment," first applied to a desert rock plane by McGee and later used extensively by Bryan, is considered synonomous with the "suballuvial bench" of Lawson, the forms described by these three writers being regarded as identical. "Pediment" is preferred, not only from considerations of priority, but also because the rock plane is not always covered with alluvium.

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[2] Exception made of possible disturbing effects of wind erosion.

[3] Gilbert, G. K., Report on the Geology of the Henry Mountains. U. S. Geogr. and Geol. Surv. of the Rocky Mountain Region, 170 pp., 1880.

[4] Bryan, K., Erosion and Sedimentation in the Papago Country, Arizona, U. S. G. S. Bull. 730, 19-90, 1922.

SIGNIFICANCE OF ROCK FANS IN THE THEORY OF LATERAL CORRASION.

Analysis of the theory of lateral corrasion early convinced the writer that the test of its validity must be sought in the comparatively narrow zone where the gently sloping rock plane of the desert floor merges with the steeper scarp of the mountain range. Examination of the rock floor far out from the base of the range need not necessarily yield evidence of discriminative value, since a plane produced chiefly by retreat of the mountain front through weathering in the manner described by Lawson[5] might look little different from one produced by lateral corrasion of streams. It is true that under certain conditions evidence of some value may be found in this zone. "Inselberge" rising sharply from throughgoing slopes which are inclined uniformly away from the parent mass, longitudinal profiles down the rock slope which are concave upward rather than convex, and rock surfaces (often covered by some alluvium) which are fresh rather than weathered, all favor an origin by stream planation rather than by weathering. But for reasons which need not be here discussed, the critical value of features in this zone is not always of the highest. Similarly, the mountain front as a whole is not the most promising field of study, since under any theory of pediment formation weathering must proceed upon the face of the range. In the zone where plane and mountain meet, however, the process of plane formation and mountain retreat should afford conclusive evidence of its *modus operandi.*

A purely theoretical study of what we might expect to find in this zone under different theories of pediment formation led to a result quite unanticipated. It became evident that if the pediment is a product of lateral planation, and the mountain front retreats mainly through trimming of its frontal spurs as the shifting streams from time to time impinge against them, the zone in question should exhibit a series of relatively flat semi-cones, or less than semi-cones. Each partial cone would appear to be an ordinary alluvial fan where deposition of debris was plentiful; but in the absence of such debris it should be a bedrock surface having the form of a typical fan, and apexing like the alluvial fan at the mouth of the canyon from which issued the sculpturing stream. That this must be the case will be evident to anyone who will visualize the geometric form described by an inclined stream relatively (but not rigidly) fixed in position at the point of issuance from the canyon mouth, and shifting more and more widely below that point. The alluvial fan is the expression of that form where deposition alone has occurred, or where considerable deposition has accompanied erosion of bedrock. The "rock fan," as I propose to call it for lack of a better name, is the same form where retreat of a mountain front has let streams operate on the solid mass of the range, and where erosion has exceeded deposition.

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[5] Lawson, A. C., The Epigene Profiles of the Desert, Univ. of Calif., Dept. of Geol. Bull. 9, 23-48, 1915.

This result of the deductive processes came as a complete surprise, and was, I must confess, treated at first with cautious skepticism. Alluvial fans were widely known features. But in many excursions through arid regions I had observed nothing resembling the "rock fans" required by this analysis, nor could I recall mention of such forms in the literature. It was not until several years of intermittent field search had been rewarded by discovery of the type example I was seeking, and after the substance of this paper had been presented before Section E of the American Association at its Pasadena summer meeting in 1931, that I found rock fans had been briefly mentioned by McGee, although not explained by him (see below, section entitled "Rock Fans of the Coyote Mountains").

It was evident, on further thought, that rock fans, if they existed, should normally be covered by alluvium, and so appear to the observer as ordinary alluvial fans. This might explain the fact that they had escaped detection by so many students of desert forms. It thus became obvious that careful scrutiny of the critical zone where plane and mountain meet must be made in many localities, in the hope of finding some few where the alluvium would be sufficiently trenched, or sufficiently washed away, to reveal rock fans if they existed. Should such search fail to find them, grave doubt must attach to the theory of pediment formation by lateral planation. On the other hand, should they be found to constitute a common feature of desert landscapes, retreat of the mountain front chiefly by weathering would seem to be excluded wherever they occur, and the validity of the weathering theory of pediment formation would be open to question.

The conclusions suggested in the last sentence preceding will be valid only in case rock fans must be carved by streams, and cannot be produced by simple weathering back of the mountain front. So far as I have been able to analyze the problem, such is the case. Lawson[6] believes that where the inner edge of the alluvial embankment consists of a series of fans, retreat of the mountain base by weathering will take place at a higher level opposite the apices of the fans than in the inter-fan depressions; and he believes also that retreat opposite the apices will proceed on a steeper slope. If we accept Lawson's reasoning, analysis will show that after the mountain front has retreated in the manner specified for a considerable distance, the residual pediment must show a sort of fluting perpendicular to the range base. Low parallel ridges having faintly concave sides will alternate with broad depressions, the vertical distance between ridge crests and depression floors progressively increasing toward the mountains. Profiles across the fluted pediment parallel to the mountain front (and hence transverse to the fluting) will be identical in character, whether made close to the mountain or far out, with a profile across a series of alluvial fans made immediately at the mountain base. But no profile across the fluted pediment can duplicate the profile secured across coalescing alluvial fans some distance out from the mountain base, where oblique transection of fan radii gives broad rounded curves convex upward. This is because the process of retreat described cannot produce rock fans with radii descending equally in all directions from apices located at the mountain base.

Bryan[7] notes that at certain localities he found the pediment surface unusually steep opposite canyon mouths, and explains the phenomenon thus: "This exception seems to be due to especially resistant boulders which have been brought down by the stream and dropped at the canyon mouth, causing the stream to spread and lose its carrying power. The boulders, until they weather into fragments small enough to be moved, protect and preserve a steeper slope than is normal to the pediment." Bryan's description suggests the presence of rock fans, although he does not recognize them as such. Hence it might be argued that more or less fan-like forms, with high apices opposite canyon mouths, could be produced by selective protection in the manner described. But a brief analysis will be sufficient to convince the reader that nothing resembling the symmetrical rock fans described in the following pages could originate in this way. One may perhaps entertain the hypothesis that hard-rock fan surfaces may in some measure be protected by an alluvial cover of coarse debris. But before the rock fan can be protected it must be formed; and the only agent competent to fashion a rock surface of sub-conical form with all radii slightly concave upward and nicely graded to the normal profile of stream transport, appears to be stream erosion. We may therefore reasonably conclude that if rock fans are found along the inner margins of pediments, the hypothesis ascribing a dominant rôle to stream action in the formation of pediments is strongly supported.

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[6] Op. cit., p. 43.

[7] Op. cit., p. 54.

FIELD SEARCH FOR ROCK FANS.

Field observations in widely separated localities soon made clear the fact that it is not easy to find the combination of conditions which will furnish conclusive proof on the critical question as to the existence or non-existence of rock fans. Cases were observed in which ravines trenching alluvial fan forms revealed bedrock beneath the alluvium; but while it was believed the bedrock also possessed the fan form, exposures were not sufficiently abundant to exclude the possibility that more or less isolated irregular foothill spurs, buried by alluvium, had been revealed by later dissection.

Examples were encountered in which a bedrock plane appeared on the surface of the fan form near its lateral borders, as if streams following along the contact of fan margin with mountain front, in the manner so frequently observed on alluvial cones and fans, had merely removed a thin veneer of alluvium from this marginal belt. A good illustration was seen near the mouth of a small, unnamed canyon on the west flank of the Ortiz Mountains in New Mexico, east of the wagon road leading from Golden to Cerrillos. Here again one was impelled to believe that he saw partially exposed a rock fan of considerable dimensions; but it was not possible to exclude the possibility that the stream, shifting laterally on a thick alluvial deposit, had merely cut into the mountain flanks for a limited distance, giving lateral rock benches of no great magnitude, such as are apparently represented by Eckis[8] in Fig. 5 of his report on alluvial fans of the Cucamonga region in California.

On the west side of the Franklin Range north of El Paso, Texas, is a series of coalescing alluvial fans beautifully terraced toward their outer margins where stream trenching shows a great thickness of alluvium. The steeply inclined upper slope of one of these fans was found to merge with a slope developed on bedrock (Fig. 1, A), the transition from alluvium to rock taking place abruptly a short distance out from the mountain scarp. This example seemed to indicate that retreat of the mountain front by lateral corrasion may cause the fan form, fashioned wholly on alluvium farther out, to develop on bedrock as the wall of the range is cut back. But so local and so tiny an illustration could not alone bear the weight of an important theory.

Better exposures near the apex of what appears to be a fairly extensive rock fan were found not far from Golden, New Mexico, at the northern base of San Pedro Mountain. An opportunity to visit this area was afforded in 1930 through the courtesy of Mr. Herbert Brooks of Albuquerque. The igneous intrusions of the range are gold bearing, and the alluvial fans flanking its base have long been worked on a limited scale as placer deposits. Prospect holes have been sunk in the fan surfaces, apparently not only to test the richness of the deposit but also to determine the depth of alluvium (10 to 25 feet in this locality) cloaking the rock floor. Near the apex of the fan in question operations with a steam shovel have exposed, in a long trench, the contact between alluvium and bedrock (Fig. 1, B). The exposure indicates that the surface of the latter is a relatively smooth plane and slopes gently away from the range. Boulders up to 3 and 4 feet in diameter rest on the plane, which has a low gradient compared with the steep mountain front. This relationship suggests that here at least the rock plane is not the product of weathering controlled by maximum size of fragments, but is the result of stream erosion. As this part of the rock plane is distinctly higher than even the alluvial covering farther along the mountain base, one is impelled to believe that the rock surface has the form of a semi-cone or fan. Unfortunately, my efforts to

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[8] Eckis, R., Alluvial Fans of the Cucamonga District, Southern California, Jour. of Geol., **36**, 224-247, 1928. See Fig. 5.

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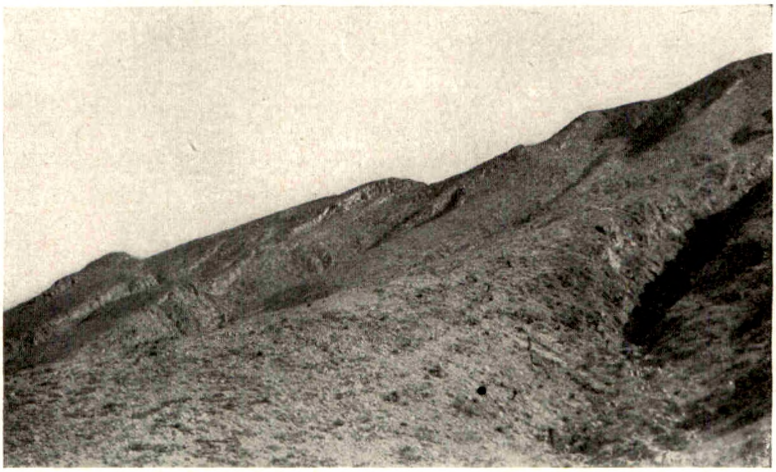

Fig. 1, A. Steep apex of fan on west side of Franklin Mountains, north of El Paso. In foreground the fan is composed of alluvium, but the upper part in right background is of bedrock, well exposed in walls of marginal ravine.

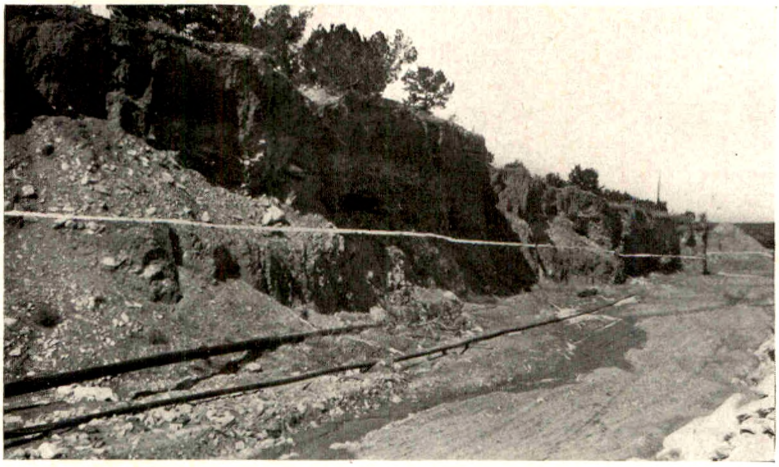

Fig. 1, B. Contact of rock plane (shown by white line) with overlying alluvium exposed in placer workings near Golden, New Mexico.

secure from the mining authorities data which would enable me to plot the depth of alluvium in a number of test pits, and so develop the form of the rock surfaces over a considerable area, have been without success.

In portions of New Zealand alluvial fans have a very striking development, and along some of the precipitous coasts of the region these are occasionally cut into by waves in such manner as to give cross-sections of fans and underlying bedrock. As observed from a boat some distance off the coast west of Wellington, the bedrock appears distinctly to rise in convex swells under the somewhat steeper convexities of the alluvial surface, as shown in Fig. 2. It was believed that the convexities of the bedrock profile have the same origin as those of the alluvial surface; that they result from sectioning, parallel to the mountain front, a series of coalescing rock fans. But the writer was unable to examine critical areas on the ground, and realizes the danger of error in long range observations.

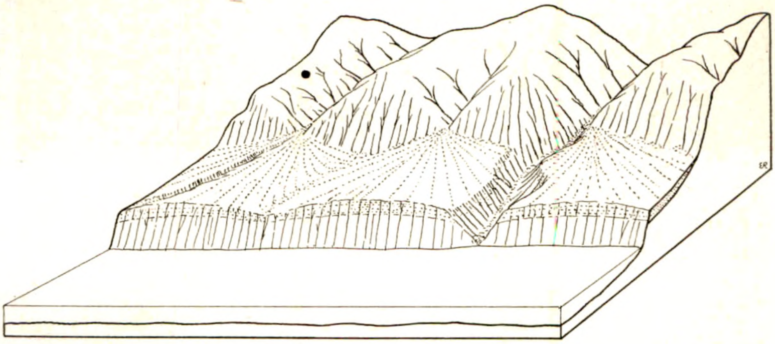

Fig. 2. Truncated fans of the New Zealand coast. Generalized sketch.

Southeast of Tucson, Arizona, at the base of the Tanque Verde Mountains, is found an excellent pediment (Fig. 3, A) slightly covered with alluvium in some of the places examined, but often showing bedrock both on the surface of the plane, and in the walls of streams which trench it to a slight depth. This pediment appeared to have the form of a low, flat cone near the mouth of an adjacent canyon; but the faintness of the slopes and the large size of the form made one hesitate, in the absence of a good contour map, to trust implicitly one's visual impressions.

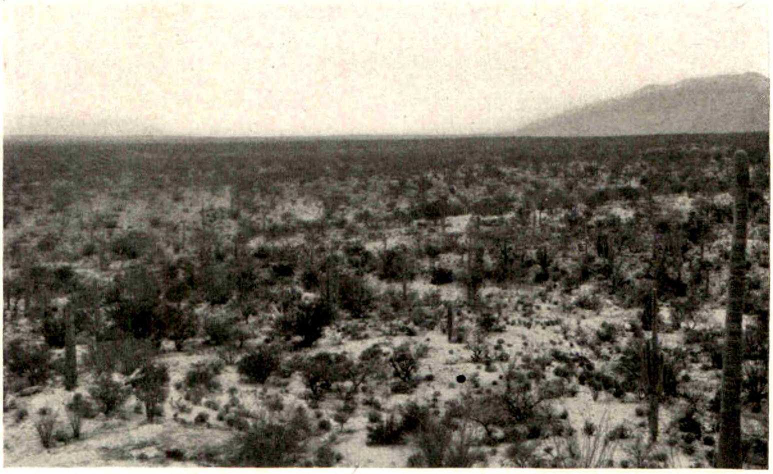

Fig. 3, A. Broad pediment, apparently fan-shaped near mountains and slightly dissected, at base of Tanque Verde Mountains, Arizona.

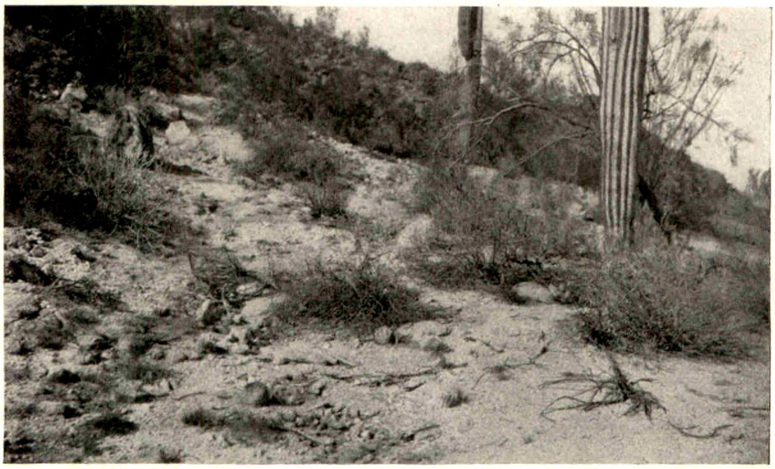

Fig. 3, B. Small and imperfect rock fan formed by rill, Sacaton Mountains, Arizona.

In the Sacaton Mountains of Arizona, on the road from Sacaton to Casa Grande, the writer had an opportunity in 1930, thanks to the courtesy of Professor J. W. Hoover of the Tempe Normal School, to examine portions of the contact of mountain scarp with the excellent pediment described by Kirk Bryan[9] in his Papago report. The angle between the two surfaces is very marked, suggesting that the two were developed under very different conditions or by different forces. The immediate angle is locally rounded, and an examination of the rounded zone revealed the presence of what appeared to be very small and imperfect rock fans, developed by small rills (Fig. 3, B). The channels of the latter sometimes followed the contact between mountain front and fan margin, in the manner frequently observed on alluvial fans. It is believed that the work of these countless rills, swinging from side to side on their miniature rock fans and repeatedly impinging against the mountain front, must in the aggregate play an important rôle in mountain front retreat. Bryan recognizes rills as a factor in desert erosion, but seemingly limits them to the previously formed pediment at the base of the mountain slope, where they tend "to reduce the height of interstream areas."[10] In the writer's opinion erosion by rills on the mountain scarp itself is an important factor in causing scarp retreat, and miniature rill-carved rock fans bordering major stream-carved rock fans are an expectable feature at the inner borders of pediments. But he realizes that the small and imperfect examples observed in the Sacaton Mountains would scarcely be convincing to one who doubts the validity of the theory of lateral corrasion.

I have deemed it worth while to present the foregoing illustrations of the difficulty of securing wholly convincing field evidence of the existence of rock fans, both to emphasize my conviction that these forms are much more widespread than is at first apparent, and to explain why they should long remain so little known despite their abundant development. Fortunately excellent examples, beautifully exposed and of undoubted authenticity, do exist. Let us now turn our attention to some examples in southern Arizona which leave no room for doubt as to their origin and their significance for the student of desert erosion planes.

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[9] Op. cit., pp. 52-58.
[10] Op. cit., pp. 55-57.

A ROCK FAN IN THE DRAGOON MOUNTAINS.

Twelve miles east of Benson, Arizona, is a broad low pass between the Dragoon Mountains and the Little Dragoon Mountains. Through this gap runs the highway known as Route 81. As the west-bound traveller emerges from the western portal he finds himself looking downward into the San Pedro Valley across the smoothly sloping rock plane shown in Fig. 4. Granite is abundantly exposed over the surface of the plane for a mile or more out from the mountain scarp, while a stream trench cut 50 to 75 feet into the rock enables one to see how neatly the surface bevels the granite and how devoid it is of alluvial cover.

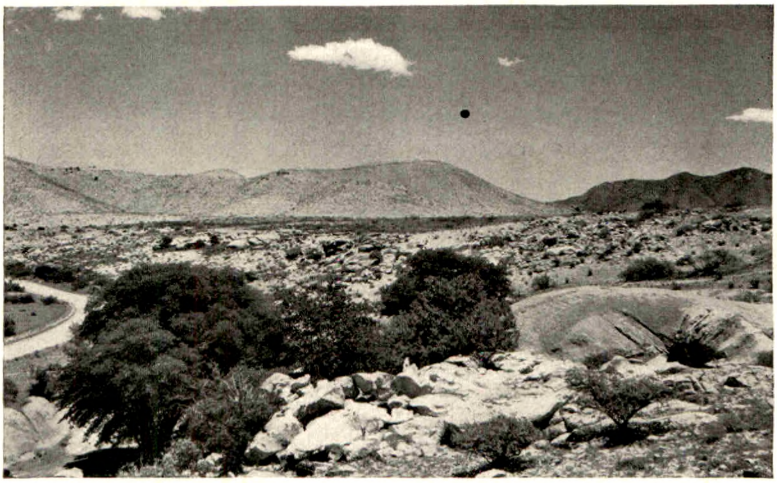

Fig. 4. Rock fan cut on granite, western side of Dragoon Mountains, Arizona. Stream trench at left, followed by road, is cut 50-75 feet below fan surface. View near apex. Compare with Fig. 5.

It was my privilege recently to inspect this plane in company with Professor F. J. Wright of Denison University. A short walk southward was sufficient to show us that at the mouth of the pass we were well above the country to the south, as well as above that to the west. In other words, the fact that we were on the high apex of a broad rock cone was

W. M. Davis and B. S. Butler I am indebted for an opportunity to visit the eastern margin of this pediment in the winter of 1930, in their joint company. I then gained a first acquaintance with the manner in which the remarkably even bedrock surface (Figs. 6, A and B) appears to emerge imperceptibly from the thinning wedge of alluvium that blankets its outer slopes. At the time of this visit I remarked what I believed might be a series of rock fans at the base of the range, some miles west of the portion of the plane examined by us. But the opportunity to study at close range the critical zone where plane and mountain meet did not present itself for more than a year.

In the summer of 1931 with the aid of my brother, S. G. Johnson of Tucson, I returned to this interesting region to test the long-distance surmises of the earlier visit. Approaching the mountains by a new route, we again noted what appeared to be a wedge-like thinning out of the alluvium and a gradual rise to the surface of the bedrock plane, the latter seemingly buried under alluvium farther east. While we made no careful study of this transition zone, which lies some four or five miles out from the base of the range, we believe the relations are identical with those reported for the partially buried pediment of Bryan, or the suballuvial bench of Lawson.

Continuing southwestward past Mineral Hill and Helmet Peak the observer journeys for some miles over the great expanse of bedrock plane, which here bevels granite for the most part, but occasionally highly metamorphosed sediments. Over broad areas the plane seems little affected by stream erosion post-dating its formation. The small wet weather streams flow on the surface of the plane, or in shallow depressions sunk but five or ten feet below its surface. Elsewhere, and especially near the mountains, the arroyos have channelled the pediment to depths of 50 feet or more, giving abundant opportunity to study both the plane surface and the rock on which it is cut.

As one nears the mountain base he notes that it is bordered by a series of very perfect fans, which to the casual observer offer no features of particular interest. In form and position they appear identical with thousands of alluvial fans seen elsewhere. Each fan has the apex of its flat semi-cone opposite the mouth of a canyon or major ravine, the fans opposite the largest canyons normally being flatter and lower than those apexing in smaller drainage basins.

At the base of the highest central peak (possibly Samaniego Peak) an unusually prominent fan (Fig. 7), heading high on the slope of the range, is extensively dissected by radial ravines; and even from afar the careful observer may note that the slopes of these ravines do not have the angle of repose with which he is familiar in channelled alluvium. One begins to suspect that the fans, like the pediment over which he is travelling, are cut on solid rock. Yet the illusion of an ordinary alluvial fan is hard to dispel. On the south side of the fan (left of view, Fig. 7), along the mountain base, one even notes distinct evidence of the presence of a marginal stream following the contact of fan surface and range front, and truncating the basal spurs of the peak, a phenomenon often observed on alluvial fans.

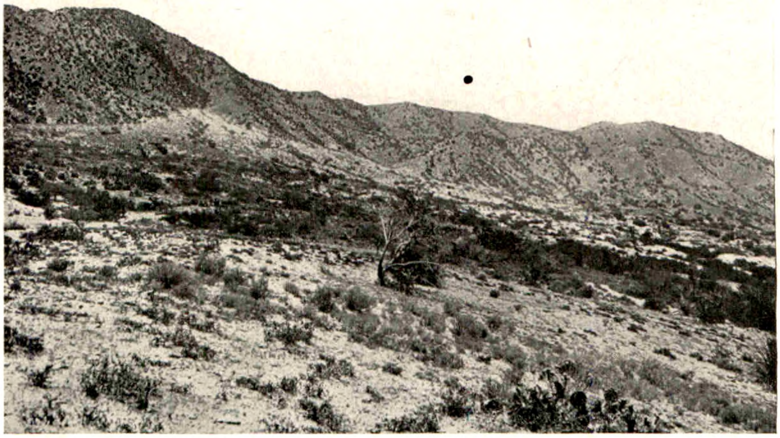

Fig. 7. Rock fan at the eastern base of the Sierrita Mountains, Arizona. Granite is exposed on all parts of the surface, now moderately dissected by recent erosion. The negative was retouched to emphasize outline of the fan, but the view correctly represents the essential relations.

A closer approach leaves no doubt of the fact that the prominent fan at the base of Samaniego? Peak is carved out of solid rock. Ledges of granite (Fig. 8, A) outcrop frequently in the radial ravines which trench the fan. Rock in place is often exposed over undissected remnants of the fan surface; but here it is usually weathered, and one is not always sure of bedrock until he finds structures locally characteristic clearly apparent. One may look southward (Fig. 5) over the rounded surface of bedrock, down into the inter-fan depression, and beyond this to the more distant fans of the main Dragoon range. The northern slope, not being visible from near the auto route, was not observed by us.

The contrast between rock fan surface and mountain front was very pronounced, the two very different types of slopes meeting at an angle which, although rounded at the immediate junction, was nevertheless very marked. Westward the rock fan gradually disappears under alluvium which in the San Pedro Valley is beautifully dissected to depths of 100 feet or more without revealing the rock floor. In this case, therefore, we seem to have a good example of a rock fan, but one which cannot be traced into continuity with any extended rock pediment farther out from the range.

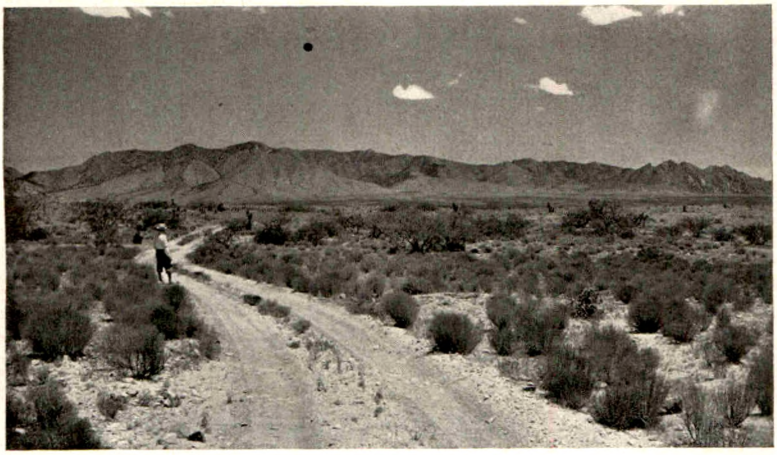

Fig. 5. Looking southward over rounded surface of same rock fan shown in Fig. 4, to more distant fans of Dragoon Mountains. Bedrock is abundantly exposed over this surface.

ROCK FANS OF THE SIERRITA MOUNTAINS.

Some 25 to 30 miles southwest of Tucson in Arizona lie the Sierrita Mountains. Bryan and Waibel have each drawn attention to the fact that this range is bordered by a broad rock plane, one of truly astonishing perfection. To Professors

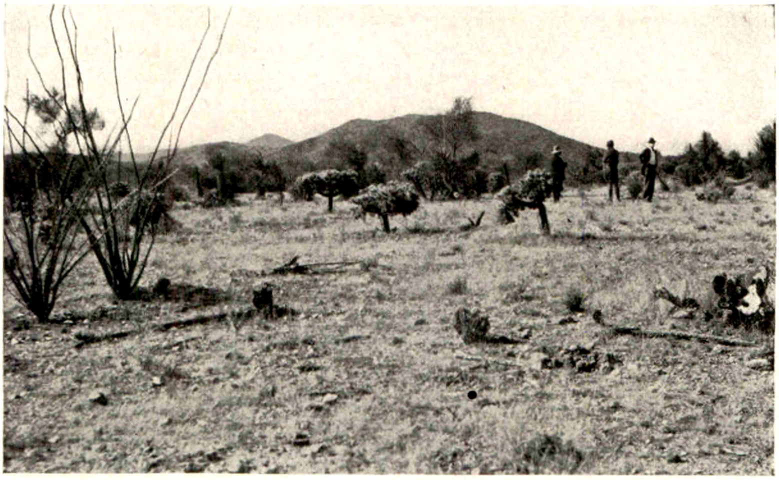

Fig. 6, A. The Sierrita pediment, Arizona, where the rock surface is undissected. Compare with 5, B.

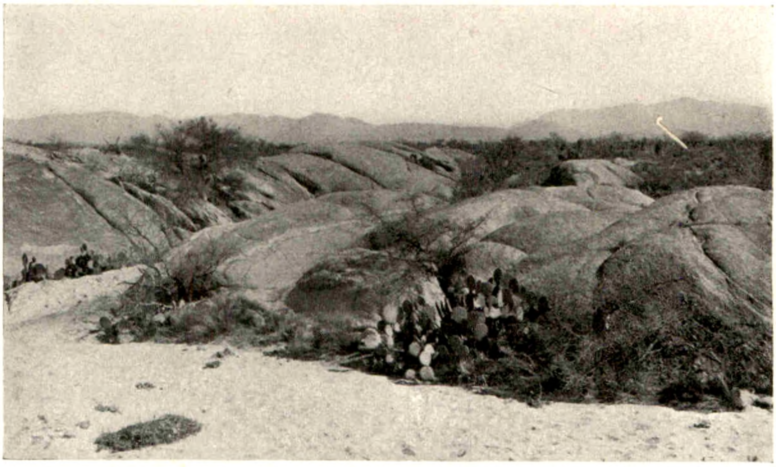

Fig. 6, B. The Sierrita pediment (same as 6, A) where slightly trenched by recent erosion.

of the granite (such as jointing and sheeting with directions corresponding to similar structures in the unaltered ledges) traversing the weathered mass. From the lower part of the fan out across the pediment, and up the steepening cone to its very apex, rock in place is abundantly exposed. Alluvium was looked for, but with the exception of doubtful material in some of the ravines none was found. Whatever debris may have been left on the fan surface by the shifting stream which carved it, time and the elements have effectually removed.

In form this rock fan is very symmetrical. The apex rises 100 feet or more above the outer margins where these meet the mountain base, while the breadth of the fan, measured along the mountain base, is something less than a mile,—both these figures being mere estimates and subject to correction. The profile along any radius is concave upward, the slope becoming sufficiently steep near the apex to make walking something of a task. Away from the range the slope decreases, and merges imperceptibly with the sloping plane of the typical pediment. There seems no room to doubt that rock pediment and rock fan are an indivisible unit, and that both owe their development to the operation of a single process. The only process which will produce both is, so far as I can see, lateral corrasion by a heavily laden, shifting stream.

Looking northward from near the apex of the fan just described, one sees in profile another rock fan. The immediate contact of fan surface with mountain front appears somewhat softened or rounded in places, as if long free from erosion by shifting streams. Elsewhere the contact is notably angular, and the evidence of lateral stream corrasion in such localities is often very clear (Fig. 8, B). But even where the contact appears rounded, the zone thus affected is a narrow one. There still remains a sharp contrast between the far-extended slopes of the steep mountain front on the one hand, and the even farther-extending gentle slopes of the combined fan-and-pediment surface on the other. My observations are thus not wholly in accord with those of Waibel[11] who cites the Sierrita Mountains as a case where the angle between mountain front and pediment is missing, the "mountains being seen to rise with gentle slope and a gradual transition from the surrounding pediment." It should be noted, however, that Waibel fully

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[11] Waibel, L., Die Inselberglandschaft von Arizona und Sonora, Sonderband der Zeitschrift der Gesellschaft für Erdkunde zu Berlin Hundertjarfeier, 1828-1928, 68-91, 1928, p. 88.

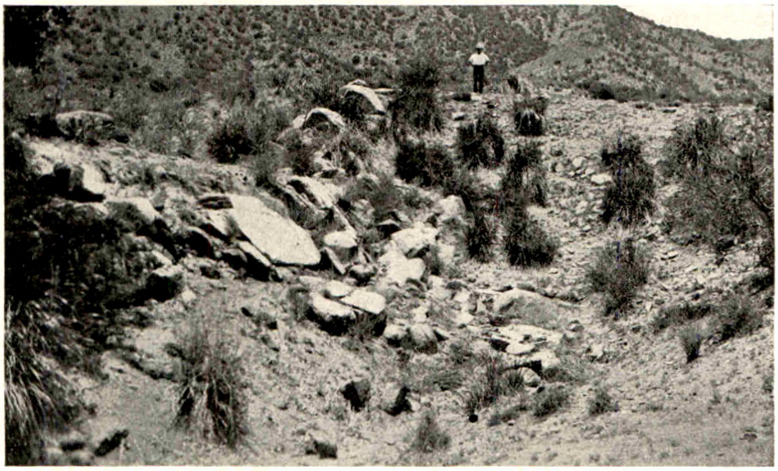

Fig. 8, A. Ledges of granite exposed in radial ravine dissecting rock fan at base of Sierrita Mountains. Rock in situ is exposed clear to surface of fan which is devoid of alluvial cover. The man is standing upon bedrock, on fan surface.

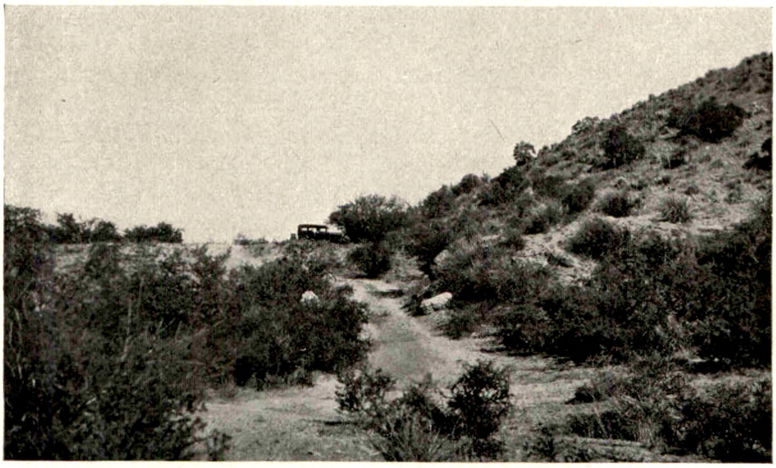

Fig. 8, B. Apex of rock fan north of Magee's Ranch, Sierrita Mountains. The automobile is on the rock surface of the fan at the base of the mountain front. Stream erosion has trenched the fan in the foreground.

recognizes the presence of this angle as a characteristic feature of desert ranges in general, and seeks to explain it as the result of "transportation of debris in rills (*Flächenspülung, Rinnenspülung*)." I am in doubt as to the precise manner in which debris transportation by rills is supposed by Waibel to create this angle, for apparently the rôle assigned to the rills is primarily the relatively passive one of removing debris. Waibel states that "the essential process (in pediment formation) is the comparatively swift recession of the escarpment by weathering of the exposed rock walls and removal of the debris from the plains."

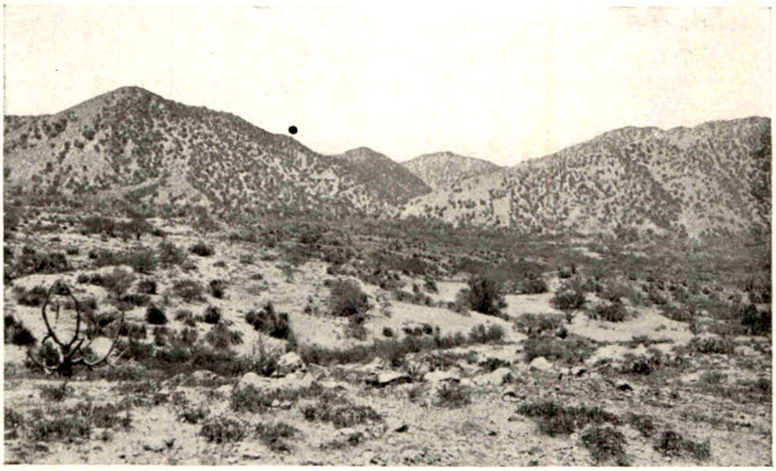

Fig. 9. Apex of low and relatively flat rock fan at mouth of large canyon just south of area shown in Fig. 7. The bedrock surface of the fan is moderately trenched by later stream erosion.

The marked contrast in slopes referred to above strongly suggests that the two types of surface have developed under control of different forces. The steep slopes of the mountain front are like those determined by the forces of weathering when operating upon scarps of any origin; the gentler slopes of fan and pediment are like those being carved by heavily laden streams in arid regions. It is difficult to see how weathering could produce two sets of slopes each of great areal extent and differing profoundly from the other in degree of inclination, the two meeting at a sharp angle or in an angle but little rounded. Had any one force produced the rock slopes, they should not be obviously separable into two distinct types, but should merge imperceptibly one into the other.

If one passes south along the mountain front, descending the southern slope of the high rock fan at the base of Samaniego? Peak (Fig. 7), he soon begins to ascend the rock surface of another fan which has its apex at the mouth of a large canyon (Fig. 9). This fan, like its neighbor described above, has granite in situ abundantly exposed over its surface. But it is much flatter than the fan to the north, and its apex is considerably lower. This is what we should expect if the fans are the product of laterally corrading streams; for the stream of greater volume, debouching from the larger canyon, will normally attain the graded condition on a slope more gentle than that of its smaller neighbor. Similar relations were observed in the fans near Golden, New Mexico, and in those of the Dragoon Mountains. While Bryan did not recognize rock fans as an element of pediment topography, his carefully recorded observations of field facts strongly suggest their presence in areas studied by him, and show the same relations of steepness of slope to size of canyon described above. Bryan[12] writes: "The angle of slope of pediments ranges from about 50 feet to 200 feet to the mile. It is noticeable, however, that in any one mountain range the slope is steeper opposite the smaller canyons and very much flatter opposite the large canyons." He notes certain exceptions, already quoted in an earlier section of this paper, where unusually steep slopes opposite the mouths of (larger?) canyons are associated with the presence of especially resistant (large?) boulders, to which latter he attributes a protective action. If the boulders are large, as seems to be implied though not directly stated in his text, even the exceptions agree with the expectable consequences of rock fan formation by lateral corrasion of streams, since a large stream heavily laden with big boulders will attain the graded condition on a relatively steep slope. It seems difficult to account for the observed nice adjustments of pediment slopes to sizes of associated streams and stream load by any theory which does not attribute to stream corrasion the major rôle in pediment formation.

Further progress toward the south along the base of the Sierrita Mountains is difficult, the rock fans close to the mountain face giving the undulating or corrugated effect which

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[12] Op. cit., pp. 53-54.

Blackwelder[13] believed to be characteristic of alluvial fans alone, while dissection of the rock fans increases the ruggedness of the topography. But one may return eastward to the originally smoother and still less dissected part of the pediment, then turn south a few miles, and again approach the base of the range near Magee's ranch. Here he finds himself once more traversing a series of coalescing rock fans, so badly dissected by recent stream erosion that fan remnants appear as mesas, or as "peninsulas" connected with the mountain base by narrow strips of the original fan surface. The apex of one of these fans is shown in Fig. 8, B, where the adjacent mountain slope has been distinctly trimmed by a lateral ravine following the contact of fan surface and mountain front. If the reader will place a straight edge tangent to the upper part of the mountain slope shown in this figure, he may readily note some trace of oversteepening of the lower part, a feature much more prominent in the field. The canyons debouching from this part of the range show inner gorges 50 feet or more in depth, presumably due to the same incision of streams which trenched the fans.

The major fan of this region has its apex more deeply re-entrant into the mountain mass than does the smaller example shown in Fig. 8, B, and is located just to the south, with Magee's ranch on a part of its surface. Bedrock is sufficiently exposed to leave no doubt as to its character; but unlike the parts of other rock fans examined in the Sierrita district, this individual is partially cloaked with alluvium. Arroyos five or six feet deep in places showed as much as four feet of angular stream gravel and sand overlying the bedrock floor; and it is probable that a more thorough inspection than we were able to give would show even greater thicknesses of alluvial cover.

The dissection of certain of these rock fans, coupled with their varying altitude opposite different canyon mouths, prompts the reflection that attempts to correlate fan remnants, where these appear as benches along the mountain front, may lead to erroneous deductions. There seems to be no reason why the upper levels of different fans produced at the same time should not show ranges of altitude amounting to some hundreds of feet. To correlate such remnants either as parts of the same erosion surface warped by differential earth movements, or as parts of successive erosion surfaces formed in different epochs, would be equally wrong. As I have already indicated,[14] we should consider the possibility that certain reported peneplanes in the western mountains, including the Rocky Mountain peneplane in central Colorado (Fig. 10), may be parts of ordinary pediments the inner borders of which

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[13] Blackwelder, E., Desert Plains, Jour. of Geol., **39**, 133-140, 1931, pp. 136-137.

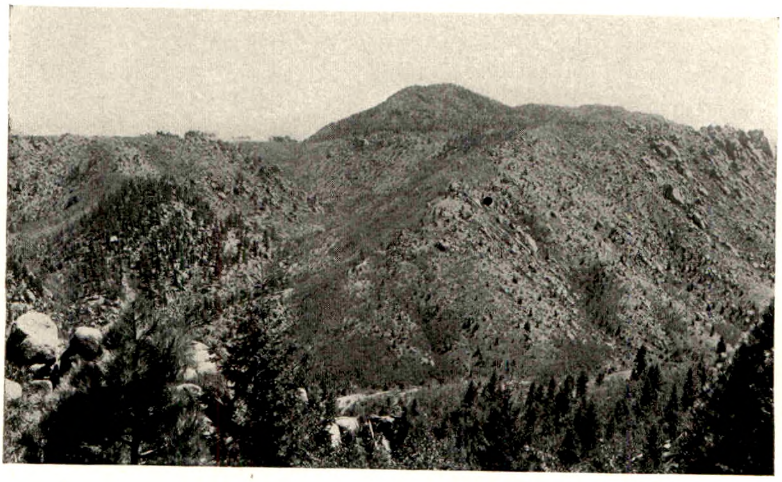

Fig. 10. "Rocky Mountain peneplane" west of Palmer Lake, Colorado, with monadnock rising above and canyon cut below its even surface. The marked eastward slope of this erosion plane, the apparent former perfection of its surface, and the "inselberg" character of some of the monadnocks, suggest that it may be a dissected high-level pediment, formerly continued across and bevelling the tilted strata of the Great Plains.

presumably, on the theory of lateral corrasion, consisted of rock fans, perhaps developed on a grand scale. May it not be that some of our difficulties in correlating remnants of these supposed peneplanes is due to the great variation in altitude of the original forms consequent upon the diverse local conditions under which they developed? And may not some of the slopes attributed to tilting, as possibly in the case of the Rocky Mountain peneplane just cited, represent the original relatively steep inner portions of extended rock pediments? If so, both the uplifts and the tiltings these forms are supposed to register may prove to be non-existent.

Whatever may be the answers to these questions, the primary significance of the rock fans of the Sierrita Mountains lies in this fact: they provide an unusually beautiful illustration of a landform the existence of which was recognized by the writer not in the ordinary course of routine field observation but solely as the result of deducing the reasonable (but in this case unexpected) consequences of a theory. The finding of these forms, following the purely deductive conclusion that they ought to exist, inevitably inspired an added measure of confidence in the theory that rock pediments, or suballuvial benches, owe their development chiefly to the corrading action of heavily laden, frequently shifting streams.

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[14] Johnson, Douglas, Planes of Lateral Corrasion, Science, **73**, 174-177, 1931.

ROCK FANS OF THE COYOTE MOUNTAINS.

Thirty-five miles southwest of Tucson, Arizona, lie the Coyote Mountains, a small mass at the northeastern extremity of the great Baboquivari range. The writer has never visited this region, but an excellent view of a portion of the Coyote Mountains is appended to W J McGee's classic paper on "Sheetflood Erosion."[15] No discussion of rock fans is given in the main text of McGee's paper; nor is there any reference to such a feature, unless an obscure passage on page 104 describing deltas and fans containing fragmental debris varying in thickness from nothing to 40 or 50 feet and resting on bedrock, and another equally obscure at the bottom of page 109 and the top of page 110 referring to the building of alluvial fans which are later planed "into gentle curves blending with the adjacent baselevel," were intended by McGee to describe alluvial fans overlying fans formed on rock. But the plates at the end of the article are accompanied by long descriptive texts, and that relating to the view of Coyote Mountains contains this short but clear and highly important observation:

> "Several low fans are shown . . . . these have the form of alluvial accumulations, but actually consist of sharply carved mountain rocks, veneered thinly with granitic loam and gravel littered with great boulders."

The fans in question are very perfectly developed as shown in the full-page plate, evidently reproduced from a good photograph. The wording of the text indicates close range, first-hand observation on the part of a competent investigator, and it therefore seems reasonably safe to include the Coyote Mountains among the localities exhibiting rock fans having a high degree of perfection.

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[15] McGee, W. J., Sheetflood Erosion, Bull. Geol. Soc. Amer., **8**, 87-112, 1897. See Plate 12, and descriptive text on page 112.

Interest also attaches to McGee's descriptive text of Plate 13 in his report, reproducing a photograph of the eastern side of the valley of Rio Magdalena, north of Imuris, Mexico. It is there stated that "the great aprons forming the background have the appearance of alluvial fans, ... yet analogy with all of the plains examined indicates that they are in greater part baseleveled mountain rocks thinly veneered with alluvial deposits. They were not visited." Reasoning from analogy is altogether unsafe in this problem, and we now know that McGee greatly over-estimated the extent of rock pediments in the southwest, and similarly under-estimated the extent of true alluvial deposits which frequently have enormous thickness. But if we must hesitate to follow this author in regarding the fans in question as necessarily composed of rock, the quotation has value in emphasizing how completely he visualized the existence of this type of desert topography.

In view of these clear statements regarding rock fans in the descriptions of McGee's plates, it seems most remarkable that his classic paper otherwise takes no account of such novel forms. Possibly the difficulty of satisfactorily explaining them as a product of sheet-flood erosion caused him to postpone discussion of this particular phase of the problem until further evidence of the precise manner of their shaping should be secured. However that may be, there remains to be explained my own failure to recall McGee's reference to rock fans in a paper which I have read more than once in the last thirty years. I can only infer that the reference (assuming I ever read the plate descriptions carefully) made no particular impression on me at a time when I saw no special significance in fan forms developed on rock; while I certainly failed to read through the long plate descriptions in later years when the significance of the reference would have appealed to me. I am indebted to Professor Davis for bringing the lapse to my attention following my discussion of rock fans at the Pasadena meeting of the American Association for the Advancement of Science. Let me add that chagrin at my remissness has been quite over-balanced by the pleasure experienced upon independent discovery of the Sierrita rock fans. Perhaps there was, after all, advantage in discovering anew field facts which met the requirements (originally unanticipated) of a theory, rather than fashioning a new explanation expressly to account for features found described in the literature.

DISSECTED ROCK FANS.

We have seen that in the case of the Sierrita fans stream dissection has already begun its work of destroying their symmetrical cone forms. When once the eye is accustomed to detect these features it will find in the foothill topography of many ranges abundant indication of former rock fans. Sometimes these will be reduced to a maze of rolling hills and ravines which still preserve distinct indications of the earlier conical shape. Occasionally the mouth of a canyon appears partially blocked by such hills, and the stream turns to one side, taking a passage which strongly suggests the course of a fan distributary following the contact of fan surface and mountain front (Fig. 11, A). Elsewhere the only trace of the former rock fan will be a dissected rock bench on one or both sides of, and sloping away from, the canyon mouth (Fig. 11, B). Here planation at a lower level has consumed most of the earlier fan, and a new cone, either of alluvium or carved on rock, may be the most conspicuous feature. Every stage of dissection has been noted, down to that of a mere rudely conical arrangement of foothills, of doubtful significance. All these forms are of interest to the student of desert morphology; but the question of origin of such forms must first be decided on the basis of those which are best preserved.

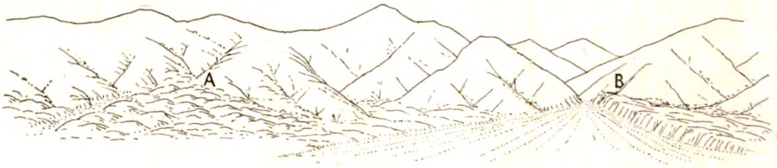

Fig. 11. Types of dissected rock fans:
A. Sub-conical mass of hills partially blocking canyon mouth, the stream escaping by marginal gorge following contact of fan and mountain front.
B. Inclined rock bench preserved on one side of canyon mouth, representing marginal portion of rock fan largely removed by planation at lower level where new fan of more gentle gradient has been formed.

SUGGESTIONS FOR FURTHER STUDY.

It is believed that the rock fans of the Sierrita pediment are alone sufficient to raise grave questions as to the validity of the theory which would account for the formation of pediments or suballuvial benches through retreat of mountain fronts chiefly by weathering, although it is fully recognized that every rock surface exposed to the air suffers some weathering effects. Neither does the process of sheet-flooding seem to offer a satisfactory explanation of these forms. They are not merely explained by, they are required by, the theory of lateral corrasion. But the theory of lateral corrasion is too important, and its implications are too far reaching, to rest on the testimony of a few localities, however clear that testimony may appear to be. Hence the need of further evidence, gathered by other students of desert forms. As a possible aid to further study I append a few notes on localities which I have had no opportunity to examine carefully, but where casual observation suggests that proper scrutiny may yield data of critical value.

Along the base of the Rocky Mountain front range, six miles north of Colorado Springs, there is a series of good fans, in part composed of alluvium but in part also of rock, to judge from distant views. In high fans near the Modern Woodmen's Sanatorium bedrock was observed in several places, alluvium 50 feet thick in others. Whether we have here a rock fan covered with alluvium, a rock fan dissected and the valleys later filled with alluvium, or a combined alluvial and rock fan, the rock having an irregular surface with projecting high points planed off tangent to fan surface, was not determined. Two miles east of the Sanatorium soft white and yellow sandstones, now carved into "hoodoo" forms, appear to have once formed part of a rock pediment capped by granite debris from the mountains. Distant views suggest that this pediment is a prolongation of the high fan at the Sanatorium, while streams trenching the high fan have opened out another partial pediment at a lower level. Both surfaces can be traced a few miles out from the mountain base, gradually approaching each other due to the fact that the later surface has a more gentle gradient than the earlier. The foregoing observations were made under wintry conditions, with snow on the ground, and are subject to correction. They merely suggest that a careful examination of the critical zone along the base of the Front Range might be fruitful.

Between Benson and Vail, Arizona, the Southern Pacific Railway is bordered on either hand by typical desert ranges. From the rapidly moving train I observed high level benches or terraces, in part undoubtedly alluvial, but in part having the appearance of remnants of high level pediments or rock fans. My notebook mentions the bases of the Rincon, Empire, Whetstone, and Little Dragoon Mountains as localities which deserve careful examination by anyone interested in the problem of rock fans.

Approaching Rodeo, not far from the Arizona-New Mexico boundary, the east-bound traveller on the Southern Pacific Railway observes to the right of the track a range of mountains exhibiting a very remarkable high-level bench sloping steeply toward the plain, to which it drops off abruptly at the mountain border. The bench is of rock deeply trenched by canyons, and appears to be the inner portion of a once far-spreading pediment, the outer portion of which has been removed by erosion of weaker beds or alluvium, or dropped by faulting. A few miles farther on, the observer notes to the left of the track a wonderful series of fans, one of which rises nearly half-way to the summit of the range it borders. This high-level fan is deeply trenched, with its apex strongly re-entrant in the range. More recent, flatter fans are developed at lower levels, and appear to be alluvial. But the high-level fans suggest by the contours of their eroded surfaces that bedrock may be present, while outlying rock hills may be remnants of greatly eroded rock fans. Still farther on (ten minutes by rail), and several miles to the right of the track, a high mountain range has a broad zone of foothills which appear to represent a high-level rock pediment or series of rock fans, which rise nearly half-way to the top of the mountain scarp. The relations resemble those in the first range discussed in this paragraph, except that the bench is more thoroughly dissected and the pediment character therefore less obvious. This whole region seems a promising one for study.

Just west of Sierra Blanca, Texas, on the north side of the highway known as Route 80, is a circular group of mountains (Sierra Blanca) bordered by high-level dissected fans and later fans showing little dissection. From a distance it appeared that rock was outcropping extensively in one of the high-level fans on the western side of the range; and the contours of neighboring high fans suggest that they should all be examined carefully with a view to determining whether or not true rock fans form an important element of the range border topography. Other ranges in this general region show varying aspects of fan topography, and deserve investigation.

North of Victorville, California, Silver Mountain is bordered by a beautiful rock pediment trenched by the Mojave River and its tributaries. As observed at long range the surface of this plane seems to show frequent outcrops of bedrock, and to merge, at the base of the range, into low, relatively inconspicuous rock fans. A close range inspection would verify or correct these impressions gained at a distance.

When ten miles west of Casa Grande, Arizona, the westbound traveller on Route 84 approaches a range of mountains near the southern end of which is a conspicuous high-level plane, apparently the remnant of a fan, below the surface of which a broad valley has been opened. Whether this fan surface was developed on rock or on alluvium could not be determined from our distant view of it; but other bench-like surfaces on the face of the range, obviously developed on rock, suggest the former existence of high-level erosion planes about these mountains. From Hammock's filling station on Route 84 the traveller can probably reach the high fan remnant, not far to the south; but the urgency of a hasty journey prevented us from satisfying our curiosity regarding its true nature.

Probably not all, and possibly none, of the areas cited above, will exhibit good rock fans. They are indicated merely as "hunting grounds" which looked promising to the writer. If any reader already possesses knowledge of the existence of rock fans in any of the localities cited in this paper, or is able to secure definite information on future field excursions, the data would make a welcome contribution to the study of rock fans and their significance in the morphology of arid regions. Pending further investigation the theory of lateral planation is presented as a working hypothesis which seemingly has much to commend it to the careful consideration of geomorphologists.

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ON THE SO-CALLED ELDEN METEORITE.*

ROBERT E. S. HEINEMAN.

A unique object of suspected meteoric origin found in 1927 near Flagstaff, Arizona, has been described by Brady.[1] The mass consists of a graphite matrix veined with irregular intersecting bands composed of grains of metallic nickel-iron. A careful search of the literature revealed no described meteorite showing the queer texture shown on a polished section of this find. (Fig. 1.) The result of a chemical analysis is repeated here.[2]

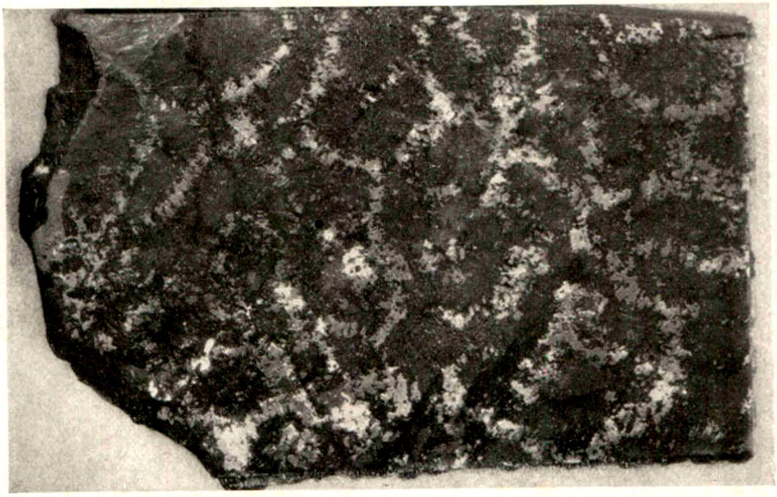

Fig. 1. Polished surface of the Elden specimen. Photograph by L. F. Brady. x 1.5.

Iron, metallic	37.440
Iron as $FeCl_3$	.680
Iron as FeO	3.287
Sulphur	.073
Silicon	.432
Manganese	.120
Chlorine as $FeCl_3$	1.300
Phosphorus	1.110
Nickel	4.040
Cobalt	.047
Carbon as graphite	46.530
Carbon, combined	2.202
Oxygen as FeO	.943
Insoluble, mainly FeO and SiO_2	1.796
	100.00

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* Published by permission of the director, Arizona Bureau of Mines.

[1] Brady, L. F., A Suspected Meteoric Specimen from Northern Arizona, this Journal, **21**, 173, 1931.

[2] Analysis by W. A. Sloane, Assistant Chemist, U. S. Bureau of Mines.

Considerable discussion arose as to the origin of the specimen and while several suggestions were offered, the meteoric theory being the most favored, the matter was still somewhat of a mystery.

In August of 1931, the writer happened to notice a specimen in the collection of the American Museum of Natural History which solved the problem.[3] This is meteorite specimen No. 10 in Dr. Reeds' office in the American Museum. It is a sliced and polished section of one of the Canyon Diablo irons. The major portion of the slice is a typical octahedrite, but the piece contains a large elliptically-shaped nodule about 6 by 8 cm. which shows exactly the same characteristics as the lump found near Mount Elden. (Fig. 2 and Fig. 3.) Veinlets of nickel-iron intersect a graphite field in the same manner and have the same appearance in both specimens. Hence it may be said that the Elden specimen is meteoric in origin, but instead of being classified as a new meteorite is a part of the Canyon Diablo fall.

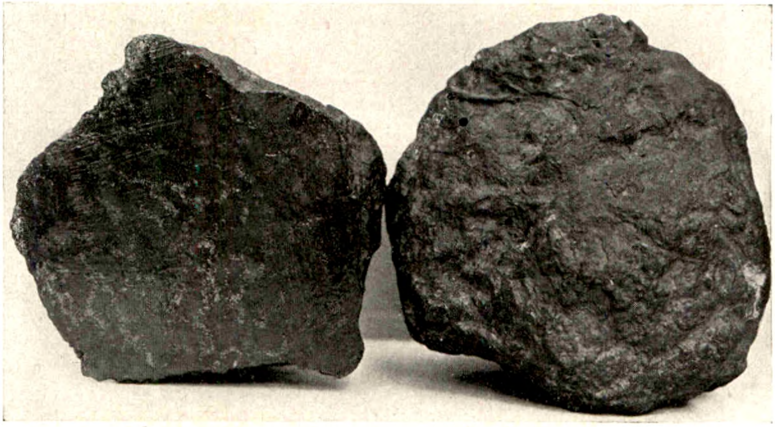

Fig. 2. The Elden nodule, sawed in two parts. Compare with Fig. 3. Photograph by L. F. Brady. x 0.5.

Brady has recalculated the chemical analysis of the Elden specimen on a basis of subtracting the graphite.[4] This gives the metallic portion a composition similar to many meteoric irons, but shows an abnormally high percentage of chlorine and combined carbon. Brady suggests that the object may have been an inclusion in a larger iron meteorite, the iron shell having been completely oxidized and removed because of the high chlorine content. Such has evidently been the case.

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[3] The specimen was discovered quite by accident. The writer wished to see the Cruz del Aire meteorite and in the absence of Dr. Reeds, the curator of geology, a search for the Cruz del Aire was necessary. While looking for it this other specimen was found.

[4] Brady, L. F., op. cit.

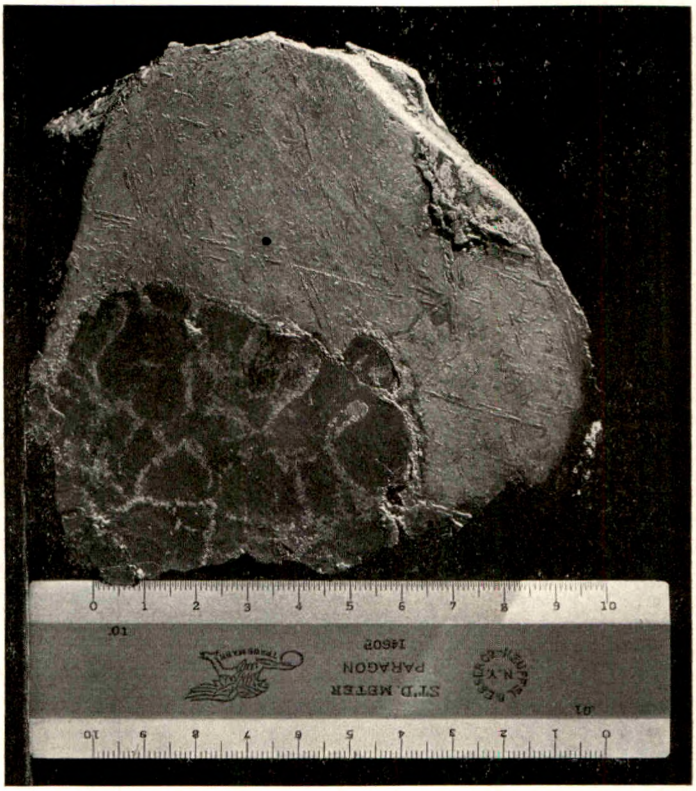

Fig. 3. Slice of Canyon Diablo meteorite with veined graphitic inclusion. Photograph by the American Museum of Natural History, New York, through the courtesy of Dr. Chester A. Reeds. x 0.68.

Nodules of graphitic material have been found in the Canyon Diablo before. One about 3 cm. in diameter associated with troilite has been described by Dr. Merrill.[5] None of these, however, have been as large as these two segregations nor have they contained the intersecting veins of nickel-iron.

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[5] Merrill, G. P., The Structure and Composition of Meteorites, U. S. Nat. Mus. Bull. **149,** 3, 1930.

Much of the Canyon Diablo meteoric material is noted for its rapid oxidation and weathering. Notably the "shale balls" described by Barringer and others. Some of these are found with nuclei of nickel-iron which, on removal of the outside shell, rapidly oxidize throughout. So it may be seen that the facts fit together well.

How the Elden portion came to the locality in which it was found is still a matter for conjecture. Flagstaff is about thirty-five miles in an air line from the Meteor Crater and is supposedly in the direction from which the meteor came. The Elden portion could have been an outrider of the main swarm or it could have been carried to its resting place by human hands.

ARIZONA BUREAU OF MINES,
TUCSON, ARIZONA.

ARTIFICIAL SPHERULITES AND RELATED AGGREGATES.

H. W. MORSE, C. H. WARREN AND J. D. H. DONNAY.

ABSTRACT.

Perfect spherulites or related crystalline aggregates, various "malformed" and aberrant forms, of over 100 slightly soluble substances have been obtained artificially by metathesis, aided by slow diffusion in jellies. Such forms are described.

Perfect spherules give, in parallel light, an interference pattern called the "spherulitic figure," somewhat similar to the figure obtained in convergent light with a uniaxial crystalline slice cut normal to the optic axis. Measurable properties of the spherulites are listed. An explanation of the peculiar optical behavior of perfect spherulites is given in simple, non-mathematical language.

"Spherulitic birefringence" is defined in contradistinction with the ordinary crystal birefringence. A partial list of measured optical data is appended, covering 67 substances.

I. THE SPHERULITIC HABIT.

In Nature crystal aggregates having a spherical form have long been known. The "spherulites" of the glassy igneous rocks are perhaps the most familiar illustration, but the mineralogist will at once recall a considerable number of minerals which frequently exhibit a spherulitic habit or one closely analagous, for example, wavellite and some of the zeolites. In the botryoidal or mammillary forms of hematite and cassiterite the individual curvatures are the surfaces of segments of spheres. Most of these forms are made up of slender, often minute crystals closely packed and radiating from a center. They often exhibit concentric zones or shells marking changes of one kind or another during growth (changes in color, for example) or pauses in the growth, the latter often accompanied by a change in the size of the constituent fibers. Certain plumose or sheaf-like aggregates are doubtless related forms and seem to have possible counterparts in some of the eccentric, artificial crystallizations to be referred to later on.

That particles of a precipitate can have a spherical form has also been frequently noticed. Some early observers were of the opinion that the first form of many precipitates was spherical and that the minute spheres afterward changed to individual crystals with plane faces which then developed as normal crystals.

Our evidence is against this opinion. As far as we know, any particle which has spherical form when it first becomes visible (resolved) under the highest power of the modern microscope, continues to grow without developing plane faces.

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All solid particles with spherical external form are aggregates, each built up of a large number of small crystal units. We have observed that growing crystals, which show definite plane faces after completion of their growth, are already bounded by plane faces from the time they reach a size sufficient to permit resolution of details under the microscope.

The range of substances which can be induced to crystallize with a spherical habit—form spherulites—is very large,[1] including compounds of almost any chemical class and substances crystallizing in any crystal system. Spherulites can be formed of many substances if the reacting solutions are allowed to mix by diffusion, avoiding all convection. Good spherulites of barium carbonate and of mercuric carbonate can be grown in ordinary dilute aqueous solution in this way. Spherulites can also be obtained by adding a nearly saturated solution of potassium iodate to a fairly strong aqueous solution of a manganous salt. Here no precautions are necessary to avoid rapid mixing or rapid growth.

In general, however, the best spherulites can be grown in a jelly and many slightly soluble substances which do not ordinarily crystallize at all well form spherulites readily in gels. A slightly soluble substance is formed by metathesis by adding one electrolyte to a sol, which is allowed to set, after which a solution of a second electrolyte is poured on the jelly and allowed to diffuse into it.

Precipitates formed in this way by metathesis in gelatine, agar, silica gel, etc., have been often studied and the presence of spherulites observed. There is wide leeway in concentration which can be used. For slightly soluble substances such as the carbonates of iron, manganese, barium and strontium, the concentration in the gel may be of the order 0.02 N to 0.05 N and that of the diffusing salt 1.0 N to 0.1 N. The solution in the jelly must, of course, be the dilute one. Either of the reacting salts may be in the dilute gelatine solution, or can diffuse in concentrated form. Gelatine is, however, easily liquefied by some substances and this will limit the choice.

Little is known regarding the factors which cause a substance to crystallize as a spherulite as against a number of normal crystals or a single crystal. It is, however, suggestive that the presence of a gel appears to be highly favorable to the growth of artificial spherulites. Furthermore, it appears to be true that the radiating fibrous masses of a number of minerals have also developed from a gelatinous state. The fact that the spherulites of volcanic rocks as well as those found in slowly cooled artificial glasses must have grown in media of high viscosity at once suggests the possibility that viscosity has an effect somewhat similar to that of gels in producing the spherulitic habit. It is altogether possible that the effect of the gel or of viscosity is to impede or perhaps prevent convection during crystallization. This supposition is also borne out by the observation recorded above that spherulites can be formed of many substances if the reacting solutions are allowed to mix, avoiding all convection.

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[1] Over a hundred substances have been examined, including hydroxides, sulphides, carbonates, bromates, iodates, sulphates, chromates, tungstates, phosphates, arsenates, ferri- and ferro-cyanides, and oxalates of the common bases. A partial list, with optical properties, is given in section V.

Special conditions may result in a departure from the perfect spherical form. Indeed, as will be pointed out later, this is frequently the case, and malformed[2] spherulites or other aberrant forms are common.

The largest and most perfect spheres have been obtained with manganese iodate and the carbonates and sulphates of barium and strontium. Spheres up to several tenths of a millimeter, perfect in form, transparency and homogeneity, have been grown. A certain amount of the medium is undoubtedly included between the fibers during growth, a fact noted by other observers.[3]

Spheres can be removed from their jelly environment, washed with hot water, and then with alcohol, dried, and mounted in any desired medium. They can also be preserved dry in air for years, without any appreciable change in their optical properties, including transparency.

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[2] It is a familiar fact that crystals are rarely geometrically perfect. Their forms, due to differential growth of the faces, look distorted in comparison with the idealized wood models used for pedagogic purposes. To this original distortion the Germans apply the term *Verzerrung*. In French, Friedel recently proposed to use the word *difformité* for the same phenomenon (see Friedel, G.: Observations sur les cristaux de sel gemme difformes, *Bull. Soc. fr. Min.*, 53, p. 143, 1930). In English no term has yet been adopted. The word *distortion* is objectionable as it implies the wrong notion that the crystal has been subjected to some mechanical deformation after it was formed. We suggest the word *malformation* which seems to convey the idea to be emphasized, *i.e.* that this type of distortion is not a superimposed structure but an original feature as old as the crystal itself.

We may, of course, apply the term *malformation* to spherulites as well as to crystals. We use it accordingly in the present paper.

[3] See Johnston, Merwin, and Williamson: The Several Forms of Calcium Carbonate, this Journal, 41, 487-89, 1916. These authors show that spherulites of calcium carbonate (probably calcite) include water up to 4%. Their spheres were formed in aqueous solutions.

Sectors and splinters obtained by crushing spheres, and sections made with the microtome clearly show the radiating fibrous structure which, in some cases, is also visible in whole spheres under the microscope.

Some spheres are unstable or in a state of strain and break up, when rubbed, with almost explosive violence. This is true of some preparations of calcium carbonate and especially of lead sulphate (see Fig. 7). They break into solid sectors or long splinters, always radially. It is probable that the individual fibers are not everywhere in contact, but are separated by inclusions of mother liquor in the residual jelly.

Perfect spheres are by no means the rule. Some substances commonly show malformed forms and others do occasionally. Malformed spheres commonly show irregular optical properties indicating the presence of more than a single center of growth or other irregularities. Curious "hour-glass" forms often appear such as the one shown by barium sulphate in Figs. 11 and 12. The two halves of such forms are symmetrical as shown by the optical properties and possess a radial structure directed from a center or centers.

The forms of Figs. 13 and 14 are both precipitates of lead carbonates taken from the same preparation. Fig. 13 shows the habit when crystal growth is rapid, near the surface where the diffusing solution enters the jelly. Fig. 14 is from a point farther down in the jelly, where the rate of change of concentration of the diffusing substance is much slower. The two halves are physically, and also optically, symmetric: each fiber on one side of the dividing plane has a fiber on the other side which corresponds to it. It will be noticed that the conditions which determine the growth of these forms are such as permit also growth in spheres.

In the case of lead carbonate, it is probable that the cross-section of the aggregate perpendicular to the long axis is circular (Figs. 13 and 14). In the case of barium sulphate it is probable that the cross section perpendicular to the long axis is not circular in all sections. Two different shapes are evident in the photograph (Fig. 11); they can be regarded as a view in plan and a view in elevation of the aggregate.

In isometric substances we have found besides the spherulites what may be called the "jackstone" form to be common. The growth in these curious forms is evidently directed along the three axial directions at right angles to each other. Fig. 17, silver phosphate, illustrates this habit as does also Fig. 18.

This shows silver chloride at a magnification of 2,000. The depth of focus of the high aperture objective used to make this picture is so small that only sections through the plane of one pair of the equal rectangular axes are clearly visible. By changing the focus, however, it can be seen in the preparation that there are arms similar to the four visible ones, one above and one below the plane of the paper (Fig. 18). Growth is directed along three axes as in the case of the silver phosphate "jackstone" of Fig. 17.

II. THE "SPHERULITIC FIGURE."

The spherulites of substances which crystallize normally in the isometric system are isotropic. The spherulites of substances crystallizing in the other systems are anisotropic and all exhibit the same type of optical behavior. Thus all of these show only one kind of interference figure. This figure, which we call "spherulitic figure," is seen in *parallel light* between crossed nicols. It shows the dark cross with its arms at right angles, in the principal planes of the nicols. When the birefringence is sufficient, concentric circles appear, black (with monochromatic light) or colored (if white light is used), corresponding to the retardation at various distances from the center. Examination of the colors shows that the retardation is zero at the center, rises to a maximum at about two-thirds of the radius, and decreases to zero at the periphery. There are, therefore, two zones in the figure where the sequence of successive retardations is the same: one within the circle of maximum retardation and the other outside this circle. It appears that all birefringent spheres, built from substances normally either uniaxial or biaxial, show the same "spherulitic figure."

III. MEASURABLE PROPERTIES.

Data which can be readily obtained by measurement are:

(a) The *diameter* (radius) of the sphere.

(b) The *maximum retardation* in the sphere as determined from the highest interference color visible in the spherulitic figure, in white light.

(c) The *distance a* from the center of the figure to the ring of maximum retardation, in white light.

Many measurements of the diameter of the circle of maximum retardation and of the diameter of the sphere indicate that the ratio $\frac{a}{r}=\frac{\text{radius of ring of max. retard.}}{\text{radius of the sphere}}$ is approximately a constant for all spherulites, although not strictly so. It varies between 0.620 and 0.660. The average of 255 measurements on 8 different preparations of spherulites is 0.648.

(d) The *distance from the center to a pair of rings* of equal retardation, one on either side of the maximum (in white light or in monochromatic light). In large spherulites, or in those having high birefringences, the distances from the center to a series of pairs of rings of equal retardation.

(e) The numerical values of all the above *retardations* (e.g., in $m\mu$).

(f) The *average index of refraction* of the sphere. In ordinary light (without polarizer) each type of spherulite has a definite index of refraction which can be determined by the usual immersion method applied to the sphere as a whole. For example:

Substance	Average index of spherulite	Indices of natural crystal	
Barium carbonate	1.54	Witherite:	1.529
			1.676
			1.677
Strontium carbonate	1.55	Strontianite:	1.518
			1.664
			1.665
Manganous carbonate	1.615	Rhodochrosite:	1.764
			1.597

(g) The maximum and minimum *indices of refraction of the fibers* (approximately) by a modification of the usual immersion method (Spangenberg),[4] applied to the spherulites as a whole (with polarizer).

(h) The maximum and minimum *indices of splinters* broken from the spherulite, by the immersion method (approximately the indices of the fibers, but possibly affected by interstitial water).

[4] Spangenberg, K., Bestimmung der Brechungsindizes von Sphärolithen, Centralblatt für Min., 408-11, 1920.

The principal indices can be determined by the usual immersion method in splinters broken from spheres. We find in this way, in monochromatic light (Na salt in the flame of the burner), at about 23° C:

For barium carbonate
$n_\gamma = 1.677, \qquad n_\alpha = 1.529.$
For strontium carbonate
$n_\gamma = 1.593, \qquad n_\alpha = 1.516.$

The splinters or smallest fibers we have been able to isolate and which we hereafter shall refer to simply as the "fibers" behave like uniaxial crystals. The axis of revolution of the ellipsoid of indices is parallel with the elongation of the splinter. We have been unable to detect the presence of a third index n_β by the ordinary immersion method.

(i) The *optical character,* + or —, of the spherulite as a whole.

The optical character of anisotropic spherulites can be determined by the usual compensation methods. The general similarity of the *spherulitic figure* with the *interference figure* of a uniaxial crystal cut perpendicular to the optic axis indicates that the same method can be applied in either case for the determination of the optical character.

Fig. 10 shows the two types of spherulites: one of high birefringence and negative optical character; the other of lower birefringence and positive. The slow ray of the quartz wedge used in taking this picture vibrates NW-SE. In the large spherulite, the retardation is compensated NW-SE; in the smaller sphere, just below it, the compensation is seen in the opposite quadrants.

In the case of the large sphere, the compensation is NW-SE. This means that the fast ray of the fiber lying in this direction coincides with the slow ray of the quartz wedge. The elongation of the fiber is therefore negative. As the fiber behaves like a uniaxial crystal, its optical character is also negative. A second method of determining the optical character of a spherulite is then to ascertain the sign of the elongation of the fibers (found by the immersion method, as described in the preceding section).

(j) The sign of the elongation of splinters (fibers) from the spherulites, is found to coincide, as would be expected, with the optical character of the spherulite.

In addition, the density of the spherulite as a whole and, by chemical analysis, impurities such as air, water, jelly could also be determined. These properties are measurable on the spherulites themselves. Several properties of the medium may have an influence on the structure of the spherulites and on the orientation of the elementary crystals in them. For example, the mechanical or elastic effect of the jelly, surface tension, adsorption.

IV. EXPLANATION OF THE SPHERULITIC FIGURE.[5]

As has been stated above, we have been unable to detect the presence of a third index n_β in isolated fibers. The third index is presumably absent because of an averaging effect produced by the random orientation of the two vibrations normal to the elongation of the fibers.

Each fiber acts like a uniaxial crystal; its optical indicatrix (ellipsoid of indices) is an ellipsoid of revolution. At the center of the spherulitic figure, the retardation is zero because the fiber to be considered is normal to the stage of the microscope and its ellipsoid, cut by a horizontal plane, gives the circular section. At the periphery of the spherulitic figure, the retardation is also zero because the thickness vertically traversed by the path of light is reduced to zero at the equator of the sphere.

Light going through the sphere along a vertical path traverses a multitude of fibers variously oriented. The retardation along such a path is the sum of the individual retardations of all the fibers traversed. Each partial retardation is the product of the birefringence of section of the fiber by the length of the vertical path of light through it, as expressed by the well-known formula $R = (n_1 - n_2)t$.

On account of its orientation each fiber has a different birefringence of section. The steeper the "dip" of a fiber (*i.e.* the larger the angle between a fiber and the horizontal), the smaller its birefringence of section and the longer the path of the light passing vertically through it.

In a vertical diametral cross-section of a spherulite, consider a series of vertical paths of light. A path located near the center of the spherulite traverses many steeply dipping fibers; the major part of its length has to be multiplied by small birefringences of section: the total retardation is small. For paths of light located farther and farther from the center, the importance of that part of the path which traverses steeply inclined fibers diminishes rapidly; larger and larger fractions of the length of the path must be multiplied by larger birefringences of section, and although the total length of the path decreases, inasmuch as it does so slowly at first, the total retardation increases. In the case of the paths of light located toward the periphery of the spherulite, the decrease in total thickness is more and more rapid, and becomes sufficient to counteract the effect of the high birefringences of the fibers inclined at a small angle on the horizontal in that region of the sphere; consequently, the total retardation reaches a maximum and decreases to zero at the periphery.

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[5] For an abstract of the mathematical theory of this phenomenon, see: *Spherulite Optics*. by H. W. Morse and J. D. H. Donnay, Am. Min., 16, 118, 1931. A more complete treatment will be given in a later paper.

V. MEASUREMENTS.

The appended table shows the optical properties of a number of spherulites. The data of the column headed "Substances" are in a few cases doubtful. Spherulites of "Copper Carbonate" were made by causing a fairly concentrated solution of copper sulphate to diffuse into a dilute gelatine solution of sodium carbonate. The solid may be a basic carbonate. The precipitate formed when silver nitrate diffuses into sodium carbonate may be the oxide and not the carbonate. The phosphates were made by diffusion into jelly containing disodium hydrogen phosphate.

Two kinds of spherulites, differing in birefringence and in many cases also in optical character, are often seen to appear in the same preparation, when one precipitate only would be expected (see Fig. 20). The two forms do not correspond to known polymorphous modifications of the substance; one of them may be another salt altogether, due to the presence of impurities in the gelatine. This is very probably the case in the formation of carbonates where the accompanying form is thought to be a sulphate. For lack of chemical analyses in the case of hydroxides, sulphates, tungstates, and iodates, we have arbitrarily ascribed to the companion form (numbered II) the same composition as that of the main form (numbered I), *i.e.* the composition to be expected from the metathesis. Needless to say, chemical analyses are exceedingly delicate to make when such minute quantities of material are at hand.

In the column headed $\frac{\text{“}R_{max}\text{”}}{2r}$ is shown the value of the maximum retardation divided by the diameter of the sphere, measured in the same units. This ratio is independent of the size of the sphere. It is not a simple function of the birefringence of the fibers, but is roughly about 0.56 of the latter.

Under "Notes" are references to known crystalline forms of the substance (chemical formula or mineral name, optical character, maximum birefringence $B = n_\gamma - n_\alpha$), as well as indications of the perfection and size of spherulites which have been measured.

PARTIAL LIST OF SPHERULITES EXAMINED

Substance	Optical Character	$\frac{R_{max}}{2r}$	Notes
Hydroxides:			
Calcium hydroxide I	—	0.070	Good spheres
Calcium hydroxide II	—	not over 0.002	
Strontium hydroxide I	+	0.065	$Sr(OH)_2.8H_2O$, (—), B = 0.023
Strontium hydroxide II ...	—	0.025	
Barium hydroxide I	—	0.060	$Ba(OH)_2.8H_2O$, (—), B = 0.030
Barium hydroxide II	—	0.009	
Magnesium hydroxide I ...	+	0.129	Brucite, (—), B = 0.020
Magnesium hydroxide II ..	—	0.049	
Lead hydroxide I	—	0.045	
Lead hydroxide II	+	very low	May be isotropic?
Copper hydroxide	—	0.060	
Cadmium hydroxide	—	0.056	Spheres to 0.02 mm.
Manganous hydroxide	—	0.009	Pyrochroite
Zinc hydroxide I	..	isotropic	
Zinc hydroxide II	..	anisotropic	Crystals only
Thallium hydroxide	—	0.054	Spheres to 0.025 mm.
Sulphides:			
Mercuric sulphide	..	isotropic	
Antimony sulphide	—	low	Stibnite, B = 1.1
Zinc sulphide	..	isotropic	Fine spheres
Manganous sulphide	+	very low	
Cyanides:			
Bismuth cyanide	..	isotropic	Spheres to 0.1 mm.
Lead cyanide	+	0.010	
Zinc cyanide	..	isotropic	Good spheres

Substance	Optical Character	$\frac{R_{max}}{2r}$	Notes
Carbonates:			
Barium carbonate	—	0.060	Witherite, (—), B = 0.148
Strontium carbonate	—	0.045	Strontianite, (—), B = 0.147
Calcium carbonate	—	0.069	Calcite, (—), B = 0.172
Silver carbonate (?)	..	isotropic	May be the oxide.
Lead carbonate	—	0.120	Cerussite, (—), B = 0.275
Copper carbonate	—	ca. 0.03	
Manganous carbonate	—	0.069	Rhodochrosite, (—), B=0.171
Cadmium carbonate	—	0.051	
Zinc carbonate	—	0.013	
Ferrous carbonate	—	0.066	Siderite, (—), B = 0.240
Cobalt carbonate	—	high	
Sulphates:			
Lead sulphate	+	0.014	Anglesite, (—), B = 0.016
Barium sulphate	+	0.006	Barite, (—), B = 0.012
Strontium sulphate I	+	low	Celestite, (—); B = 0.009
Strontium sulphate II	—	low	
Calcium sulphate I	+	0.007	Gypsum, (+), B = 0.009
Calcium sulphate II	—	very low	Anhydrite, (+), B = 0.044
Silver sulphate	—	0.006	Spheres to 0.3 mm.
Bromates:			
Silver bromate	+	0.030	Large spheres
Barium bromate	+	very low	Large spheres
Strontium bromate	..	isotropic	Or very low birefringence
Phosphates:			
Silver phosphate	+	very low	May be isotropic
Barium phosphate	+	......	
Zinc phosphate	+	0.003	
Calcium phosphate	+	low	
Tungstates:			
Barium tungstate I	+	0.003	
Barium tungstate II	+	0.009	
Strontium tungstate	+	low	
Manganous tungstate	+	0.035	
Cadmium tungstate	..	very low	May be isotropic
Lead tungstate	+	low	
Iodates:			
Lead iodate I	+	0.030	
Lead iodate II	+	0.013	
Manganous iodate I	—	0.080	
Manganous iodate II	—	0.002	
Barium iodate I	..	......	
Barium iodate II	—	......	
Cadmium iodate	+	......	
Thallium iodate	—	0.057	
Arsenates, Arsenites:			
Cobalt arsenate	..	isotropic	
Barium arsenate	+	low	
Cadmium arsenate	+	......	
Barium arsenite	—	low	Spheres to 0.03 mm.

Substance	Optical Character	$\frac{R_{max}}{2r}$	Notes
Chromates:			
Barium chromate	+	low	
Strontium chromate	—	low	Spheres to 0.05 mm.
Calcium chromate	—	high	
Lead chromate	+	high	
Nickel chromate	+	high	
Ferro-cyanides:			
Lead ferro-cyanide	+	0.018	Good spheres
Cadmium ferro-cyanide ...	—	very low	Spheres to 0.025 mm.
Ferri-cyanides:			
Lead ferri-cyanide	+	0.018	Spheres to 0.03 mm.
Cadmium ferri-cyanide ...	—	very low	
Manganous ferri-cyanide ..	..	isotropic	Or very low
Thallium ferri-cyanide ...	+	very low	
Oxalates:			
Barium oxalate	+	low	
Copper oxalate	+	0.009	Spheres to 0.02 mm.

It will be noticed that the "spherulitic birefringence" of certain substances (some hydroxides) is considerably higher than their "crystal birefringence."[6] The reverse is true for other compounds (carbonates).

The table also shows that many substances which ordinarily do not form good crystals give perfect spherulites.

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[6] The "spherulitic birefringence" of a substance being defined as the maximum birefringence of the fibers constituting a spherulite of that substance; the "crystal birefringence," as the maximum birefringence of crystals of the same substance. A rough estimate of the spherulitic birefringence may be obtained by increasing the value of R_{max} : 2r (listed in the third column) by about 80% (see approximate formula for maximum retardation in *Spherulite Optics, op. cit.*).

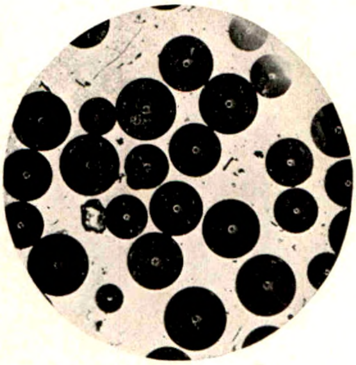


Fig. 1

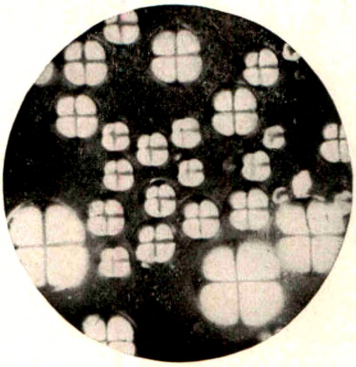


Fig. 2

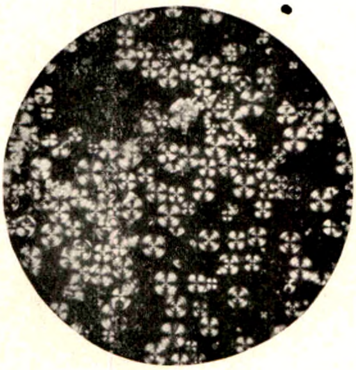


Fig. 3

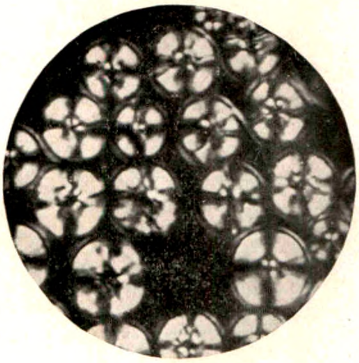


Fig. 4

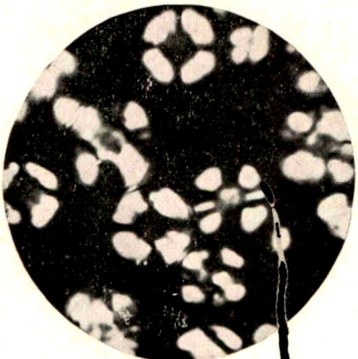


Fig. 5

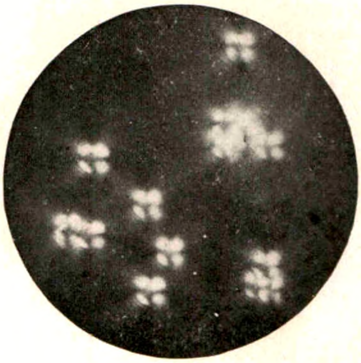


Fig. 6

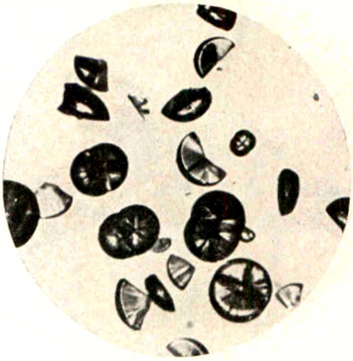
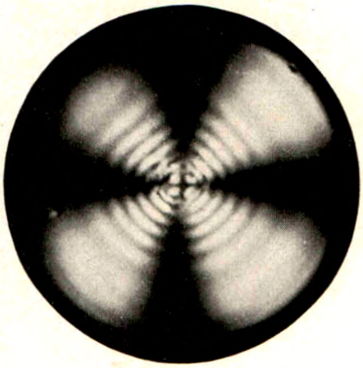


Fig. 7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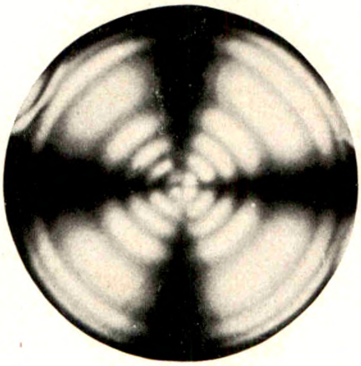


Fig. 9

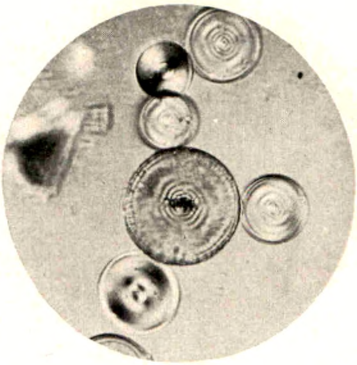
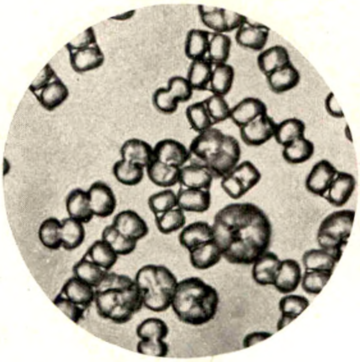


Fig. 10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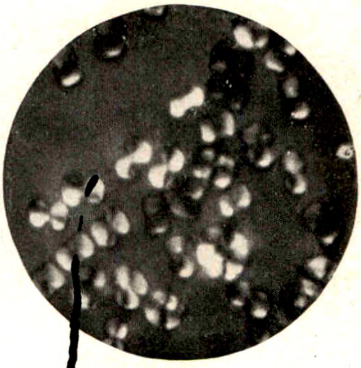
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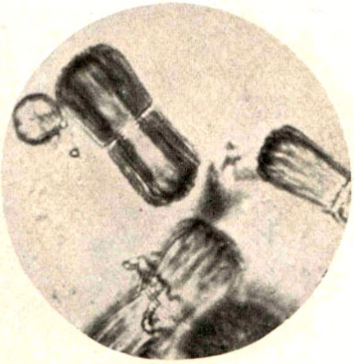
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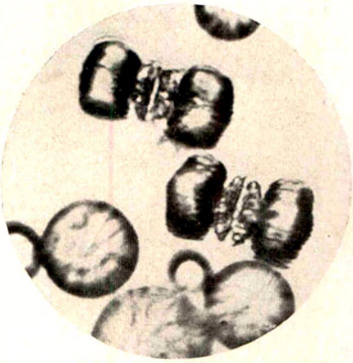
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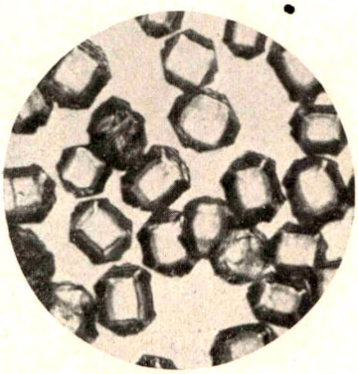
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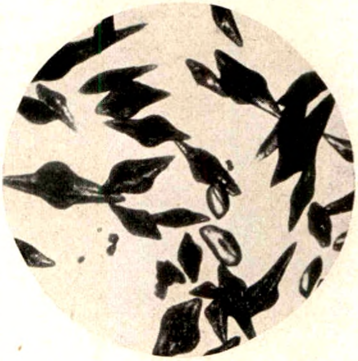
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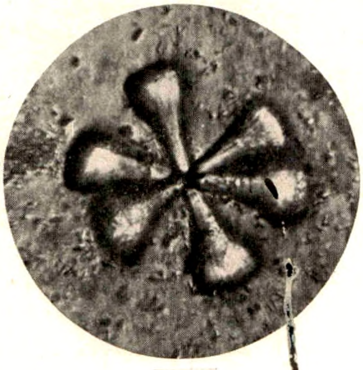
Fig. 17

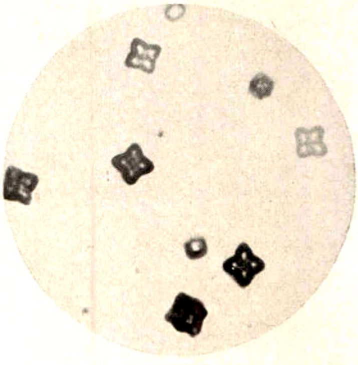
Fig. 18

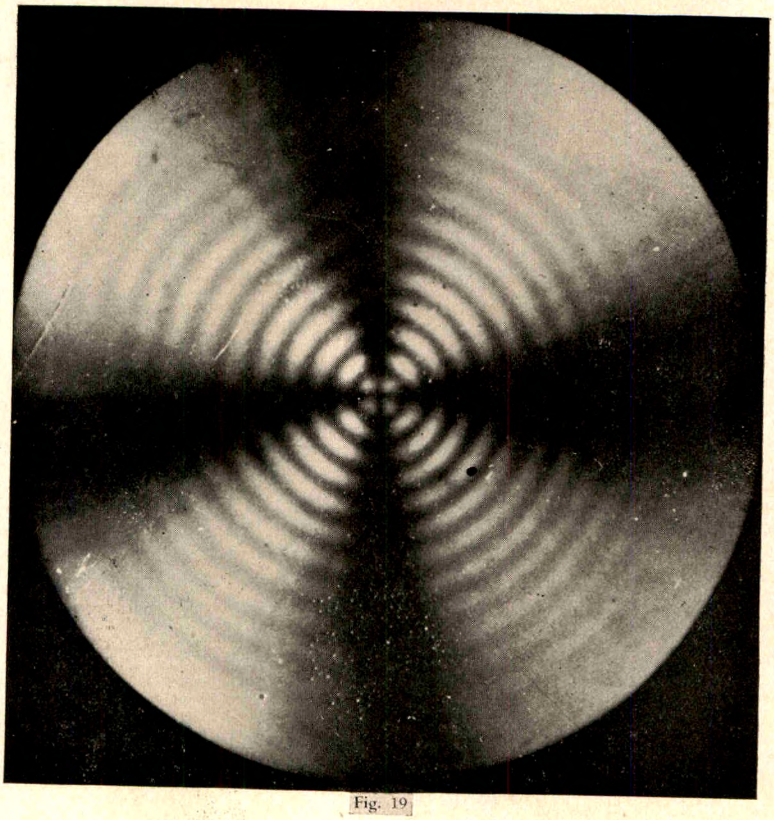

Fig. 19

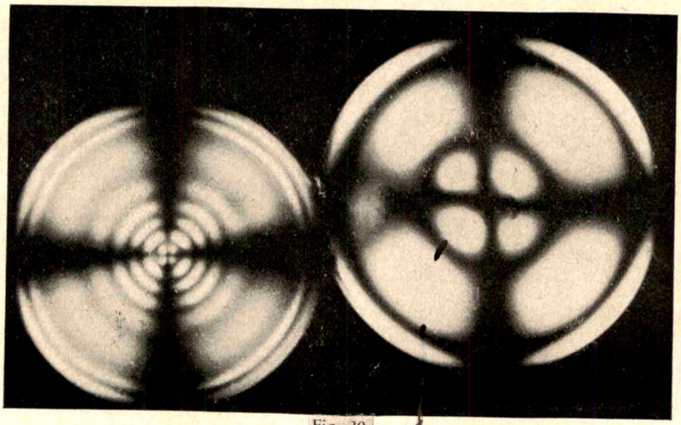

Fig. 20

DISCUSSION OF THE FIGURES.

All the precipitates shown in the figures were obtained in gelatine.

Fig. 1. Manganous iodate. x 43. In air. Ordinary light. Showing the perfect circular section. These spheres are nearly all malformed at the center, but become perfect as growth proceeds.

Fig. 2. Barium tungstate. x 93. In water (gelatine). x nicols. Perfect spheres. Low birefringence. Highest color in first order yellow. Index of spherulites much higher than that of the medium.

Fig. 3. Strontium carbonate. x 67. In balsam. x nicols. Index of medium about the average index of the spherulites. Colors into third order. Characteristic appearance of medium size spherulites of substances with rather high birefringence.

Fig. 4. Ferrous carbonate. x 333. In balsam. x nicols. Colors into second order. Many spheres malformed or cracked. The substance is not well crystallized in the ordinary precipitates obtained in the laboratory.

Fig. 5. Cadmium hydroxide. x 1,000. In water (gelatine). x nicols. Malformed. First order colors. Substance not well crystallized in the usual precipitates.

Fig. 6. Mercuric oxide (or hydroxide?). x 1,200. In water (gelatine). x nicols. The spherulites are good, but too small to permit of accurate measurement of optical properties.

Fig. 7. Lead sulphate. x 23. In balsam. Ordinary light. No perfect spherulites in the picture; all are doublets. The aggregates split spontaneously into sectors and splinters on standing in balsam for a month. Proof of radial structure.

Fig. 8. Strontium hydroxide. x 270. In balsam. x nicols. Badly malformed at center, becoming more regular as growth proceeds. Birefringence fairly high (*ca.* 0.10).

Fig. 9. Barium carbonate. x 466. In balsam. White light. x nicols. Rings into fourth order. Colors on both sides of maximum are clearly visible, including two orders between maximum and periphery.

Fig. 10. Barium carbonate. x 133. In balsam. White light. x nicols and quartz wedge. The slow ray of the quartz wedge vibrates NW-SE. The large spherulite (in the center of the picture) is negative in character and shows colors into the fifth order; the compensation is seen in the NW-SE quadrants. The sphere just below it is

positive; its highest color is compensated NE-SW. The birefringence of the negative spheres is about 0.100; that of the positive spheres, about 0.014. The exact chemical nature of the positive spheres is still somewhat in doubt. Probably barium sulphate.

Fig. 11. Barium sulphate. x 270. Ordinary light. A very common type of fibrous aggregate. "Hour-glass" or "dumb-bell" shaped. Some malformed spherulites. Good spherulites were formed in another part of the same preparation.

Fig. 12. Barium sulphate. x 270. The same field as in Fig. 11, but here with crossed nicols. The definite symmetric orientation of fibers in the two halves of the aggregate is plain.

Fig. 13. Lead carbonate. x 270. Ordinary light. Symmetrically directed by a central plane. The optical properties are like those of the hour-glass aggregates of Fig. 11. These grew at a point where the change of concentration of the diffusing substances was rapid.

Fig. 14. Lead carbonate. x 270. Ordinary light. The same preparation as Fig. 13, but the aggregates of Fig. 14 were grown at a point where diffusion was slow and growth correspondingly slow. Fibrous aggregates, with the fibers symmetrically oriented about a central plane.

Fig. 15.[7] Strontium sulphate. x 270. Ordinary light. Artificial celestite. Tabular crystals lying on (001). Measurement of interfacial angle for vertical prism (110) gives 76°. The common habit of strontium sulphate in gelatine. Spheres are also present.

Fig. 16. Lead hydroxide. x 37. Ordinary light. Curved surfaces are usual in gelatine. It is hard to determine whether these are malformed crystals or aggregates.

Fig. 17. Silver phosphate. x 366. Ordinary light. "Jackstone" type, peculiar to substances belonging to the isometric system. Growth directed along three axes at right angles, and equal in directing power. This shape can be visualized as the three diagonals of an octahedron.

Fig. 18. Silver chloride. x 1,333. Ordinary light. Similar in every way to Fig. 17, except that the arms are not so long. Three dimensional rectangular cross, with all arms equal.

Fig. 19. Manganous iodate. x 800. Crossed nicols and monochromatic (red) light. This is the central part of the spherulitic figure. About twelve orders are visible.

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[7] The junior author gratefully acknowledges the helpful criticism received in oral discussion with Professor Steinmetz, Technische Hochschule, Munich.

The photograph includes about one-fourth of the spherulite. The maximum was estimated to be at about the thirtieth order; it was not visible in the preparation.

Fig. 20. x 400. x nicols. Two forms of spherulites in the same preparation. The left-hand one, negative in character and with rather high birefringence (*ca.* 0.100) is barium carbonate; the right-hand one, positive in character and lower in birefringence (*ca.* 0.014), is probably barium sulphate. These two forms were obtained by letting concentrate $BaCl_2$ diffuse into gelatine which contained Na_2CO_3 in dilute solution. The formation of a sulphate may be accounted for by the presence of impurities in the gelatine.

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SPHERULITE OPTICS.

H. W. MORSE AND J. D. H. DONNAY.

I. INTRODUCTORY.

This paper may in a sense be considered as a continuation of *"Artificial Spherulites and Related Aggregates,"* an investigation of a broader scope and a more general character, published jointly with C. H. Warren in this Journal.[1] The aim of the present study is restricted to the mathematical explanation of the optical phenomena displayed by perfect artificial spherulites.[2]

Part of the optical measurements necessary for this study were made at Stanford University in the laboratory of Dr. Austin F. Rogers, to whom sincere thanks are due for the kind interest he took in this work.

The authors gratefully acknowledge the helpful mathematical advice received from Professor H. A. Kramers of the University of Utrecht and Professor J. V. Uspensky of Stanford University.

HISTORICAL NOTE.

No mathematical study of the optics of artificial spherulites is found in the literature, although spherulites have often been produced artificially.[3]

Natural spherulites, it is true, have been investigated but the spherulites which occur in nature are much larger than their tiny artificial replicae, and never as perfectly spherical. It is obvious then that the optical phenomena displayed in a slice cut through a natural spherulite will differ from those observed in a preparation where light is allowed to pass through a complete spherule such as we have obtained in the laboratory. This explains why no complete theory of spherulite optics could be reached by the early investigators who had only fragmentary experimental observations at their disposal.

The beautiful studies of Emile Bertrand were apparently the first work on the subject (1880). The only mathematical theory was given by Ernest Mallard (1881).

In his first paper,[4] Bertrand describes the following phenomenon, brought to his attention by Fouqué. If a section cut through a spherulite of calcium carbonate be examined in parallel light between crossed nicols, a cross and a series of concentric rings will appear when the tube of the microscope is slightly raised or lowered so as to throw the image somewhat out of focus; this phenomenon cannot be observed in convergent light. Bertrand states that the cross and rings thus obtained are exactly similar to those shown in convergent light (not visible in parallel light), by a slice of calcite cut perpendicular to its optic axis.

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[1] Am. J. Sci., 23, 421-439, 1932.

[2] Preliminary results were presented by Dr. Austin F. Rogers on behalf of the authors at the Toronto meeting of the American Mineralogical Society, December, 1930. See Am. Min., 16, 118, 1931.

[3] F. Fouqué and A. Michel-Lévy, for instance, in their work on artificial production of barium, strontium, and lead feldspars corresponding to oligoclase, labradorite, and anorthite (Bull. Soc. fr. Min., 3, 124-7, 1880), mention the fact that they found lead anorthite in spherulitic form.

[4] Bull. Soc. fr. Min., 3, 58-62, 1880.

Bertrand makes the definite statement that spherulites of biaxial crystals will not show the rings and again, that "the phenomenon of the cross and rings, shown by the spherulite as a whole, is restricted to uniaxial crystalline substances which assume the spherulitic form and are sufficiently birefringent." The fact that *rhabdophane* occurs in optically positive spherulites is to him evident proof that this mineral must be uniaxial and positive. He examined four positive substances (quartz, rhabdophane, plumbogummite, voltzite) and three negative ones (calcite, rhodochrosite, smithsonite).

He speculates on the nature of the phenomenon and offers a qualitative explanation which he himself disproves experimentally one year later (1881). His corrected view[5] is that, by throwing out of focus, the point of convergence of the light rays (focus of the objective) must be displaced in such a way as to be on the same side of the thin section as the point of convergence of the fibers (center of the spherulite). For a slice cut above the center of a spherulite, the tube must be lowered; it must be raised in the case of a section cut through a spherulite below its center. If the thin section be turned upside down on the stage of the microscope, the rule is reversed.

Bertrand writes that the spherulitic phenomena characterize the observed mineral and afford a means of determining its crystalline type (uniaxial, and whether positive or negative).

Mallard[6] gives a simple mathematical treatment of the phenomenon described by Bertrand, *i.e.* the cross and rings observed in a slice cut through a natural spherulite. He uses an approximation which is of the same type as that introduced in our simplified solution (see Section IV, 4).

II. OPTICAL PHENOMENA.

Artificial spherulites are either isotropic or anisotropic.

Anisotropic spherulites, examined in parallel light between crossed nicols, show the *"spherulitic figure"*: a *black cross* with spreading arms in a series of *concentric colored rings* of equal retardation. The retardation increases from zero at the center to a maximum at about two-thirds of the radius from the center, then decreases from this maximum to zero at the periphery. In monochromatic light, the concentric rings are black and the retardation (or path-difference) varies by one wave length from one ring to the next. The spherulitic figure of strontium carbonate as seen in monochromatic light ($\lambda = 605\ m\mu$), drawn to scale and photographed, is shown here (Fig. 1); the circle of maximum retardation is dashed.

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[5] Bull. Soc. fr. Min., 4, 60-1, 1881.

[6] Bull. Soc. fr. Min., 4, 66-9, 1881. There is a misprint in Mallard's paper: instead of b', read b^2 (*op. cit.*, p. 67, foot-note).

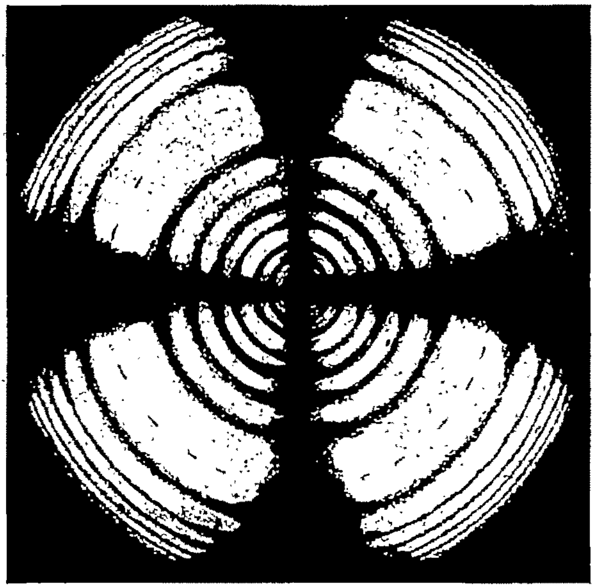

Fig. 1. Spherulitic figure of strontium carbonate in monochromatic light ($\lambda = 605\ m\mu$). Photograph of a drawing made to scale. Diameter of the spherulite: 98.6μ.

Birefringent spherulites may be said to be, optically, either positive or negative. Their optical character is determined by the usual compensation method as applied to the interference figure of a uniaxial crystal cut normal to the optic axis.[7]

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[7] Note that this *interference figure* requires the use of convergent light, whereas the *spherulitic figure*, similar in appearance, is obtained in parallel light. A comparison between these two related phenomena will be found in Appendix II.

III. EXPERIMENTAL RETARDATION CURVE.

1. *In Monochromatic Light.*

The diameter $2r$ of the spherulitic figure and the diameters of the concentric black circles are measured by means of an eyepiece micrometer. The retardations R of these circles are, from the center outwards: λ, 2λ, 3λ, . . . $n\lambda$, $n\lambda$, . . ., 3λ, 2λ, λ. The zone of maximum retardation lies between the two circles with retardation $n\lambda$. The last outward circles are crowded together at the periphery of the spherulitic figure and their radii cannot be measured.

The diameter of any black circle can be represented by $2r \cos \phi$. The values $\frac{R}{2r}$ of the retardation divided by the diameter of the sphere are plotted against $\cos \phi$. An experimental curve of the retardation is thus obtained, which is independent of the size of the spherulite.

2. *In White Light.*

The same curve can be obtained by measuring the radii of the concentric colored circles, as above, and determining the corresponding retardation by means of a compensator.

IV. THEORETICAL

1. *Fundamental Principle.*

Fresnel's classical theory leads to the statement that the retardation in a slice cut from a crystal is a function of: (1) the nature of the crystal, (2) the thickness of the slice, (3) the orientation of the section in the crystal. The latter determines the difference $n' - n''$ of the two semi-axes of the ellipse cut by the section in the ellipsoid of indices of the crystal under observation. This function $n' - n''$ is often called the ***birefringence of the section***, in contradistinction with the ***birefringence of the crystal*** (***maximum birefringence***) $n_\gamma - n_\alpha$.

For a given crystal, this law is expressed by the formula

$$R = (n' - n'')t, \qquad [1]$$

in which: R = retardation of the slice; $n' - n''$ = birefringence of the section; t = thickness of the slice.

When two crystalline slices are superposed, their retardations will be added if their ellipses of section have their major axes parallel; they will be subtracted, if the major axes are at right angle.[8]

When several slices are superposed, the total retardation will be equal to the sum of the individual retardations of the slices, provided all the ellipses of section have the same orientation.

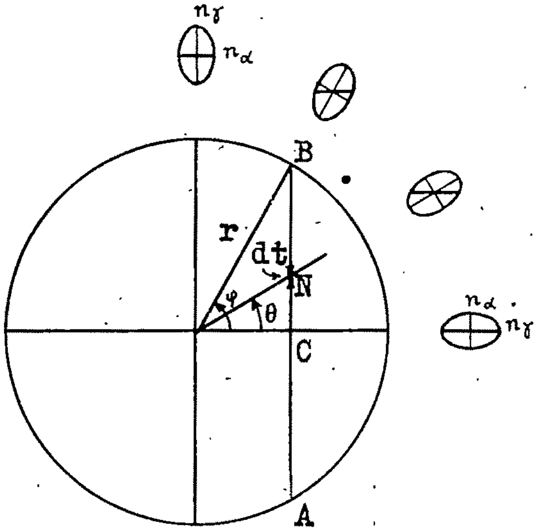

Fig. 2. Vertical diametral cross-section of a spherulite.

2. *Internal Structure of the Spherulite.*

A spherulite is made up of a multitude of fibers, radially arranged. Each fiber behaves like a uniaxial crystal. Whether each fiber actually is a single uniaxial crystal or whether it is an aggregate of component unit crystals, either uniaxial or biaxial, is a matter for speculation. It is easy to understand how the piling up of biaxial unit crystals along a radius may account for a uniaxial behavior of a fiber built up in that way. For the mathematical treatment which follows, we shall consider each fiber as a uniaxial entity, optically either positive or negative,[9] oriented in such a way that its optic axis lies along a radius of the spherulite.

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[8] By *ellipse of section*, we mean the intersection of the ellipsoid of indices with the plane of the thin slice cut from the crystal. When two ellipses of section have their major axes parallel, the slower ray of one slice coincides with the slower ray of the other slice. When the two ellipses have their major axes at right angle, the slower ray of one slice coincides with the faster ray of the other.

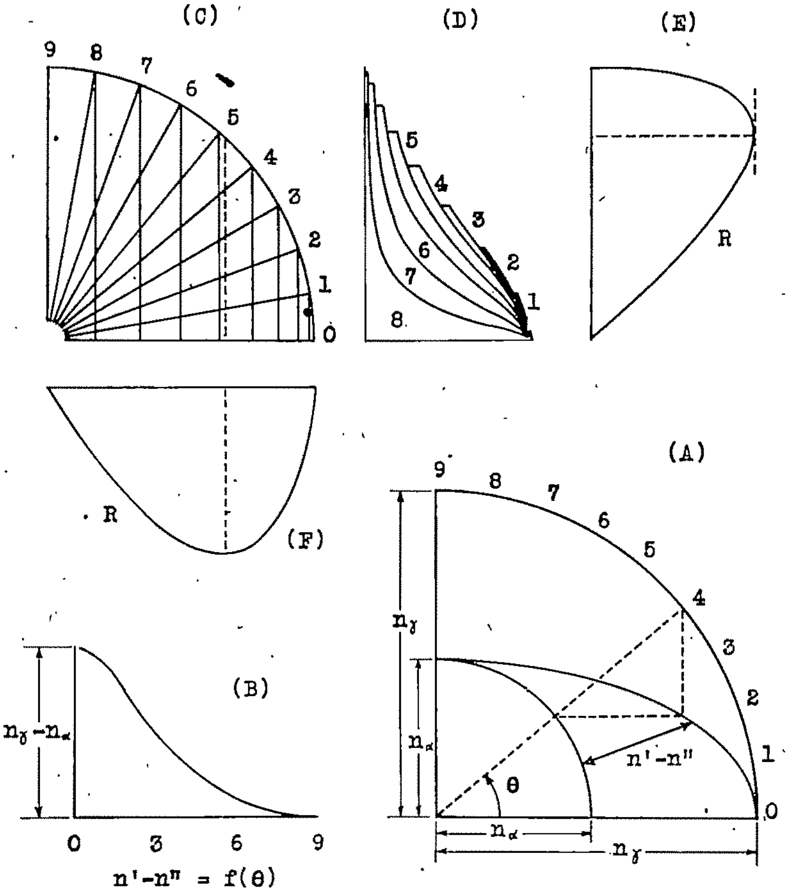

Fig. 3. Graphic integration of retardation. Case of an optically positive spherulite. The difference between n_γ and n_α exaggerated on purpose.

3. *Graphic Solution.*

The problem can easily be solved by graphic methods.

We shall only take up here the case of optically positive spherulites. Let us consider a path of light *AB* through a vertical diametral cross-section (Fig. 2). Such a path may be taken to be a vertical straight line. This assumption disregards minor deviations of the light due to refraction at the boundary between two adjacent and differently oriented fibers; it also ignores the influence of the small amount of water (or gelatine) which can be expected to have filled interstices between fibers during the formation of the artificial spherulite by diffusion in a gel.

---

[9] It may be well to recall that the optical character of the spherulite is the same as the sign of elongation of the fibers: optically positive fibers have a positive elongation and form positive spherulites.

Light passing through the sphere along a path *AB* encounters numerous fibers at different inclination (θ varying from $-\phi$ to $+\phi$). The birefringence of section $n' - n''$ will vary from $n_\gamma - n_\alpha$[10] to 0, when θ increases from 0 to $\frac{\pi}{2}$. The law of this variation may be explained as follows:

At each point *N* of *AB*, a differently oriented ellipsoid of indices must be considered. This ellipsoid is prolate in the present case (positive spherulite) and its axis of revolution makes an angle θ with the horizontal. The prolate ellipsoid is shown outside the circle in the vertical cross section (Fig. 2). A plane of horizontal section cuts an ellipse in this ellipsoid. The minor semi-axis n'' of the ellipse of section is perpendicular to the plane of the drawing, and constantly equal to n_α. The major semi-axis n' is shown in heavy line in the plane of the drawing (Fig. 2); it varies from n_γ to n_α when θ increases from 0 to $\frac{\pi}{2}$. The birefringence of section $n' - n''$ may be constructed as follows (Fig. 3, A).

An ellipse is drawn with its semi-axes equal to n_γ and n_α. For every value of θ taken between 0 and $\frac{\pi}{2}$, $n' - n''$ is given by the difference between the radius vector of the ellipse and the radius n_α of the small circle. The birefringence of section $n' - n''$ can also be plotted against θ in rectangular coördinates (Fig. 3, B).

The retardation along *AB* is twice that along *CB* (Fig. 2) by reason of symmetry. The retardation along *CB* can be represented by an area obtained by plotting horizontally against the ordinate *CN* an abscissa equal to the value of $n' - n''$ measured on the diagram (Fig. 3, B) for the corresponding value of θ.

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[10] We use the following notations for the *principal refractive indices* of the fibers, which behave like uniaxial crystals: n_γ, maximum index; n_α, minimum index. In the present case (positive fibers): $n_\gamma = \epsilon$ and $n_\alpha = \omega$.

The method is shown here (Fig. 3, C and D) in a qualitative way: the difference between the principal indices being purposely greatly exaggerated. Eight vertical paths through the sphere are considered numbered from 1 to 8 (Fig. 3, C). The retardations for these paths are represented by eight areas, designated accordingly (Fig. 3, D). These areas are superposed, the area No. 8 covering part of the area No. 7, and so on. Each area extends down to the lower left corner. The construction of such an area has been explained above: the value of the function $n' - n''$ is taken from the rectangular diagram $n' - n''$ against ϕ (Fig. 3, B) and plotted horizontally (Fig. 3, D) against an ordinate corresponding to the point of intersection of the radius considered with the path of light (Fig. 3, C). Eight points are thus available to construct the area No. 8 representing the retardation along the path No. 8; seven points are used to determine the area No. 7, and so on.

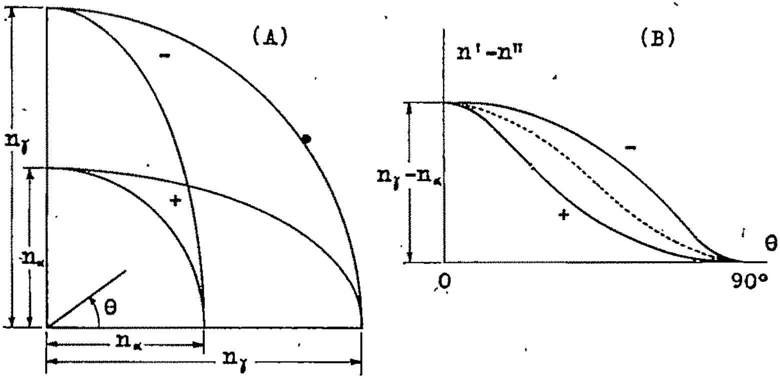

Fig. 4. Construction of the curve $n' - n'' = f(\theta)$ for both positive and negative spherulites.

These eight areas are measured by means of a planimeter (or by any device for graphic integration) and the values obtained are plotted against either *sin* ϕ (Fig. 3, E) or *cos* ϕ (Fig. 3, F). A tangent, vertical in Fig. 3, E, horizontal in Fig. 3, F, graphically determines the position and value of the maximum retardation.

4. *Simplified Analytical Solution.*

The diagrams giving $n' - n''$ in terms of ϕ (Fig. 3, A and B) have been constructed in the case of positive spherulites ($\epsilon = n_\gamma$; $\omega = n_\alpha$), when $n' - n'' = n' - n_\alpha$. They would be modified in the case of negative spherulites ($\epsilon = n_\alpha$; $\omega = n_\gamma$), when $n' - n'' = n_\gamma - n''$. In the latter, the birefringence of section is given by the difference between the radius n_γ of the large circle and the radius vector n'' of the ellipse.

The rectangular diagram $n' - n''$ plotted against θ is reproduced here for both positive and negative spherulites (Fig. 4). This shows that the value of the retardation will be different for positive and negative spheres.

In a first approximation, we can disregard this difference and consider an intermediate curve (dotted curve of Fig. 4, B), which will hold whatever the optical character of the spherulite may be. The equation of this curve is

$$n' - n'' = (n_\gamma - n_\alpha) \cdot \cos^2 \theta. \qquad [2]$$

Most textbooks give the expression of the birefringence $n' - n''$ of a section in terms of the maximum birefringence $n_\gamma - n_\alpha$ and the angles δ' and δ'' which the normal to the section makes with the optic axes:

$$n' - n'' = (n_\gamma - n_\alpha) \ \sin \delta' \sin \delta''.$$

This expression is derived from the Fresnel formula (relative to the difference between the squares of the velocities) by neglecting the square of the difference between any two velocities.

In uniaxial crystals, the above formula becomes

$$n' - n'' = (n_\gamma - n_\alpha) \ \sin^2 \delta,$$

which is identical with [2] as δ is the angle between the normal to the section and the optic axis, so that $\delta = \frac{\pi}{2} - \theta$.

These formulae are approximations only. G. Cesàro[11] first pointed out the importance of the exact value of the birefringence of section.

A simpler way of obtaining [2] is by using an approximate expression for the radius vector of the ellipse. Such an expression is obtained by neglecting the square of the difference $n_\gamma - n_\alpha$ between the two semi-axes. The radius vector is then, for positive spherulites,

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[11] See: Formule générale donnant la biréfringence d'une lame cristalline . . .", Min. Mag., 17, 163-72, 1915.

$$n' = n_\alpha \sin^2 \theta + n_\gamma \cos^2 \theta,$$

and for negative spherulites,

$$n'' = n_\gamma \sin^2 \theta + n_\alpha \cos^2 \theta;$$

whence

$$n' - n'' = n' - n_\alpha = n_\gamma - n'',$$

leading to the formula [2].

According to the fundamental principle, the retardation R along a path AB (Fig. 2) is given by the integral

$$R = 2\int_{\theta=0}^{\theta=\phi} (n' - n'')\,dt, \qquad [3]$$

in which $n' - n''$ and dt must be expressed in terms of θ.

The value of dt is obtained immediately by differentiation (Fig. 2):

$$t = r \cos\phi \tan\theta$$

and

$$dt = r\cos\phi \frac{d\theta}{\cos^2\theta} \qquad [4]$$

Substituting [2] and [4] in [3] leads to a very simple integration:

$$R = 2r\,(n_\gamma - n_\alpha)\cos\phi \int_0^\phi d\theta,$$

whence

$$\frac{R}{2r} = (n_\gamma - n_\alpha)\,\phi\cos\phi, \qquad [5]$$

in which R is the retardation along a vertical path subtending an angle 2ϕ at the center in a sphere of radius r (Fig. 2).

The maximum retardation occurs for $\frac{dR}{d\phi} = 0$, *i.e.* for $\cot\phi = \phi$, at $\cos\phi = 0.652$ or $\phi = 49°17'30''$ ($\pm$ 15″). Value of the maximum:

$$\frac{R_{max}}{2r} = 0.561\,(n_\gamma - n_\alpha).$$

Other simplified solutions may be obtained if one replaces the two curves of $n' - n''$ (Fig. 4) by other simpler lines, such as a straight line or a cosine curve. The linear approximation is better than the cosinusoidal, but neither is very satisfactory.

5. *Complete Analytical Solution.*

For simplicity in mathematical formulation, it is advisable to use here the notations ϵ and ω. The index ω is the radius of the circular section of the ellipsoid of revolution; the index ϵ is equal to one-half of the axis of revolution. It must be kept in mind that in the case of positive spherulites $\epsilon > \omega$ so that $\epsilon = n_\gamma$ and $\omega = n_\alpha$, whereas the reverse is true for negative spherulites: $\epsilon < \omega$, $\epsilon = n_\alpha$ and $\omega = n_\gamma$.

We have seen that the birefringence of section $n' - n''$ is a function of θ, given, for both positive and negative spheres, by the difference between the radius vector of an ellipse and the radius of a circle (Fig. 4, A). Both functions can be embodied in one formula:

$$n' - n'' = \pm\left(\frac{\omega\epsilon}{\sqrt{\epsilon^2 \sin^2\theta + \omega^2 \cos^2\theta}} - \omega\right), \qquad [6]$$

to be taken with the + sign in the case of optically positive spherulites and with the — sign for negative spherulites. In the first case, $n' - n''$ is the difference: radius vector of an ellipse minus radius of a circle; in the second case, it is the reverse: radius of a circle minus radius vector of an ellipse.

Substituting [6] and [4] in [3], we arrive at the following expression for the retardation:

$$R = \pm\, 2r\left(\epsilon\omega \cos\phi \int_0^{\phi} \frac{d\theta}{\cos^2\theta \sqrt{\epsilon^2 \sin^2\theta + \omega^2 \cos^2\theta}} - \omega \sin\phi\right), \quad [7]$$

with the same convention of signs as in [6].

The above integral can be solved by development into series. We may write

$$\sqrt{\epsilon^2 \sin^2\theta + \omega^2 \cos^2\theta} = \epsilon\sqrt{1 - \delta \cos^2\theta},$$

in which

$$\delta = \frac{\epsilon^2 - \omega^2}{\epsilon^2}, \qquad [8]$$

We know that $\frac{1}{\sqrt{1+x}}$ can be developed into a convergent series:

$$\frac{1}{\sqrt{1+x}} = 1 - \frac{1}{2}x + \frac{1.3}{2.4}x^2 - \frac{1.3.5}{2.4.6}x^3 + \ldots,$$

provided $0 < |x| < 1$. This condition is here satisfied for the function $\frac{1}{\sqrt{1-\delta\cos^2\theta}}$. The first three terms of the development will suffice, as the series converges very quickly. We obtain in that way:

$$\frac{1}{\sqrt{1-\delta\cos^2\theta}} = 1 + \frac{1}{2}\delta\cos^2\theta + \frac{3}{8}\delta^2\cos^4\theta + \ldots$$

and

$$\frac{R}{2r} = \pm\,\omega\cos\phi\left[\frac{1}{2}\delta\,\phi + \frac{3}{32}\delta^2(2\phi + \sin 2\phi) + \ldots\right]. \qquad [9]$$

The value of δ given by [8] must be introduced with its sign in the formula [9]. The latter will be taken with the sign corresponding to the optical character of the spherulite to which it is to be applied.

6. *Solution by Means of Elliptic Integrals.*

Another complete solution, mathematically perhaps more elegant, can be expressed in terms of Legendre's elliptic integrals[12] of the first and second classes. Details of this solution will be found in Appendix I. We shall here merely state our results in terms of Legendre's notations.

If $\Delta = \sqrt{1 - c^2\sin^2\theta}$, where the *modulus* c is always positive and smaller than one, the elliptic integrals of the first and second classes may be written respectively:

$$F(\phi) = \int^{\phi}\frac{d\theta}{\Delta} \text{ and } E(\phi) = \int_0^{\phi}\Delta\,d\theta.$$

When the *amplitude* ϕ equals $\frac{\pi}{2}$, these integrals are called *complete elliptic integrals* and designated by F_1 and E_1.

We arrive at the following expressions:

(a) In the case of optically negative spherulites ($\epsilon < \omega$), letting

$$c^2 = \frac{\omega^2 - \epsilon^2}{\omega^2};$$

$$\frac{R}{2r} = -\frac{\omega}{\epsilon}\sin\phi\left(\sqrt{\epsilon^2\sin^2\phi + \omega^2\cos^2\phi} - \epsilon\right) - \epsilon\cos\phi\,F(\phi) + \frac{\omega^2}{\epsilon}\cos\phi\,E(\phi). \qquad [10]$$

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[12] A. M. Legendre: Traité des fonctions elliptiques et des intégrales Eulériennes, vol. 1 (Paris, 1825); vol. 2 (1826); vol. 3 (1828).

(b) In the case of positive spherulites ($\epsilon < \omega$), letting

$$c^2 = \frac{\epsilon^2 - \omega^2}{\epsilon^2},$$

$$\frac{R}{2r} = + \frac{\omega}{\epsilon} \sin\phi\left(\sqrt{\epsilon^2 \sin^2\phi + \omega^2 \cos^2\phi} - \epsilon\right) + \omega \cos\phi\ (F_1 - E_1) - \omega \cos\phi\left[F\left(\frac{\pi}{2} - \phi\right) - E\left(\frac{\pi}{2} - \phi\right)\right]. \quad [11]$$

In each case, the curve is computed by points and the maximum determined graphically.

V. CHECK BETWEEN THEORETICAL RESULTS AND EXPERIMENTAL DATA IN A CONCRETE CASE: EXAMPLE OF STRONTIUM CARBONATE NEGATIVE SPHERULITES.

The foregoing theory, applied to the study of optically negative artificial spherulites of strontium carbonate affords a remarkable check between theory and experiment.

1. *Measurements.*

The negative optical character of these spherulites was ascertained by means of the quartz wedge.

Although very small (they average 0.05 mm. in diameter), these spheres can easily be crushed between a glass slip and the blade of a knife. They yield fragments and splinters, some of them remarkably acicular in shape. The principal refractive indices of the fibers were determined on such needle-like splinters by the usual immersion method and an Abbé refractometer. For Na light, at a temperature of about 23° C, the following values[18] were found:

$$\epsilon = n_\alpha = 1.516, \quad \omega = n_\gamma = 1.593,$$

giving a maximum birefringence $n_\gamma - n_\alpha = 0.077$.

The splinters exhibited a negative elongation, as expected. The measurements of indices, repeated several times, consistently gave the same value for n_γ, showing the uniaxial behavior of the fibers. It may be objected that the difference between n_γ and n_β was so small that it escaped detection. If this were true, we would be justified in considering the fibers as uniaxial, for our purpose.

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[18] It is very interesting to note the discrepancy between these values and the constants of strontianite:

$$n_\alpha = 1.516, \quad n_\beta = 1.664, \quad n_\gamma = 1.666, \quad n_\gamma - n_\alpha = 0.150.$$

2. *Computation of the Theoretical Curves.*

The values of the principal indices are introduced in the equations [5] and [9]. The corresponding curves $\frac{R}{2r}$ are computed by points (Fig. 5).

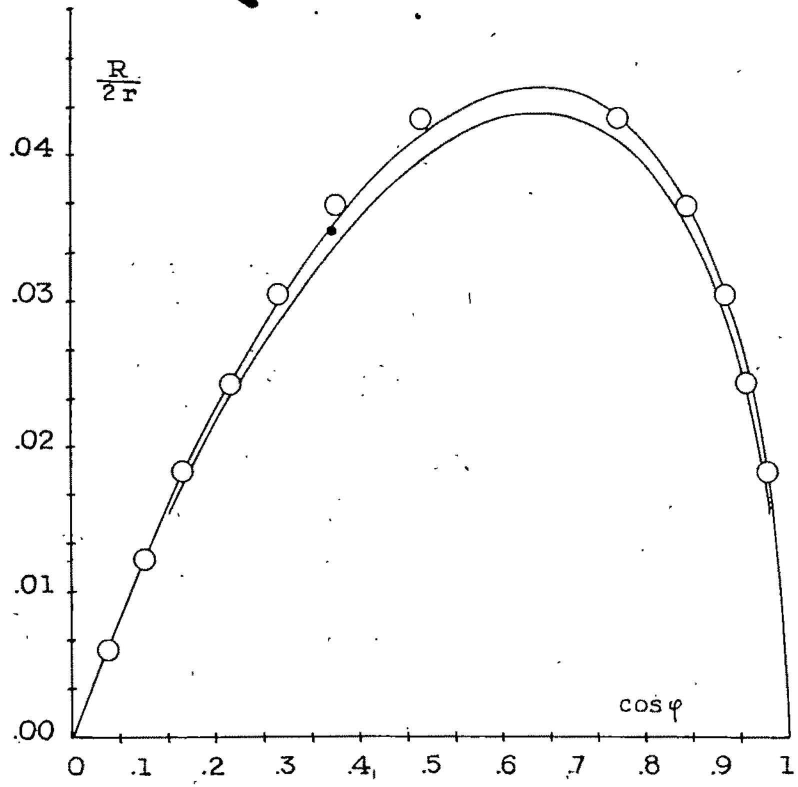

Fig. 5. Check between theory and experimental data for optically negative spherulites of strontium carbonate. Upper curve is curve (9) obtained by development into series. Lower curve is curve (5) given by the approximate solution. The centers of the circles represent points found by direct measurements.

A few results of our computations are tabulated below for the equations [5] and [9]. The curve [10] is disregarded as it almost coincides with the curve [9], passing slightly above the latter.

PRINCIPAL THEORETICAL VALUES OF $\frac{R}{2r}$, COMPUTED FOR SPHERULITES OF $SrCO_3$(—).

ϕ	*cos* ϕ	$\frac{R}{2r}$, curve [5]	$\frac{R}{2r}$, curve [9]
10°	0.9848	0.0132	0.0132
20°	0.9397	0.0252	0.0252
30°	0.8660	0.0349	0.0350
40°	0.7660	0.0412	0.0415
50°	0.6428	0.0432	0.0438
60°	0.5000	0.0403	0.0412
70°	0.3420	0.0322	0.0331
80°	0.1737	0.0187	0.0193

3. *Experimental Curve.*

Points of the experimental curve of $\frac{R}{2r}$, constructed as explained above (section III, 1), are also plotted in Fig. 5 (in circlets) to permit comparison. The numerical values of these measurements for $SrCO_3$ (—) are listed below. The spherulite on which the measurements were made was 98.6 μ in diameter.[14] Monochromatic light was used ($\lambda =$ ca. 605 mμ).

EXPERIMENTAL VALUES OF $\frac{R}{2r}$ FOR A SPHERULITE OF $SrCO_3$(—).

cos ϕ	ϕ	R(mμ)	$\frac{R}{2r}$
0.053	86°58′	605	0.0061
0.103	84° 5′	1210	0.0123
0.157	80°58′	1815	0.0184
0.222	77°10′	2420	0.0245
0.290	73° 9′	3025	0.0307
0.370	68°17′	3630	0.0368
0.485	60°59′	4235	0.0429
0.765	40° 6′	4235	0.0429
0.858	30°54′	3630	0.0368
0.912	24°13′	3025	0.0307
0.942	19°37′	2420	0.0245
0.974	13° 6′	1815	0.0184

4. *Discussion and Conclusions.*

The maximum value of the ratio $\frac{R}{2r}$ occurs at *cos* $\phi = 0.652$ and equals $0.561 \times 0.077 = 0.043$, according to the approximate solution [5]. Graphically, by drawing a horizontal tangent to curve [9], it is found to be equal to 0.045 and to occur at $\cos\phi = 0.647$ (Fig. 5).

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[14] Unless the optical change due to the introduction of the upper nicol is carefully compensated, one must be careful to measure the diameter of the spherulite between crossed nicols. In the usual type of polarizing microscope, there is an appreciable shrinking of the image when the analyser is pushed into the tube.

The experimental points are somewhat above curve [9] for values of $\cos\phi$ ranging from 0.3 to 0.6. By using curve [10] instead of curve [9], the deviations of the experimental points from the theoretical curve would be reduced by about one-fourth, as shown in the following example:

ϕ	$\cos\phi$	$\frac{R}{2r}$, exper.	curve [9]	curve [10]
60°59′	0.485	0.0429	0.0417	0.0420

The departure of the experimental points from the theoretical ordinate is 0.0012 when curve [9] is used; it is only 0.0009 with respect to curve [10]. Increased accuracy in the measurements might possibly justify the use of curve [10] instead of curve [9].

The theoretical curve [9] agrees very closely with the observed facts. It is only valid for negative spherulites whose splinters have the following refractive indices: $\epsilon = 1.516$, $\omega = 1.593$; such as $SrCO_3$ (—).

The simplified curve [5] holds for all spherulites, either positive or negative, which have the same maximum birefringence 0.077 as $SrCO_3$ (—), irrespective of the values of the indices themselves. This approximate solution, which is especially remarkable for the simplicity of its computation, also gives a very satisfactory picture of the general trend of the phenomenon.

APPENDIX I.

ON ELLIPTIC INTEGRALS.

Elliptic integrals have been widely applied in several sciences, such as geometry (*e.g.*, to determine the length of an arc of an ellipse), mechanics (*e.g.*, to solve the problem of the motion of a simple pendulum), balistics (where a classical example is found in the study of the motion of a projectile moving against a resistance proportional to the cube of its velocity), etc. As far as we know, however, elliptic integrals have not been used by crystallographers.

For those of our readers who are not already familiar with the question, and in order to spare them tedious search in mathematical texts, we give here the method used to transform the integral encountered in equation [7] into a function of elliptic integrals of the first two classes.

1. *Transformation formula.*

The first step is differentiation of a certain expression, followed by transformation to a suitable form.

$$\frac{d}{d\theta}\left(\tan\theta\sqrt{\epsilon^2\sin^2\theta+\omega^2\cos^2\theta}\right)=\frac{\sqrt{\epsilon^2\sin^2\theta+\omega^2\cos^2\theta}}{\cos^2\theta}+\frac{(\epsilon^2-\omega^2)\sin^2\theta}{\sqrt{\epsilon^2\sin^2\theta+\omega^2\cos^2\theta}}$$

$$=\frac{\epsilon^2-\epsilon^2\cos^2\theta+\omega^2\cos^2\theta}{\cos^2\theta\sqrt{\epsilon^2\sin^2\theta+\omega^2\cos^2\theta}}+\frac{(\epsilon^2-\omega^2)\sin^2\theta}{\sqrt{\epsilon^2\sin^2\theta+\omega^2\cos^2\theta}}$$

$$=\frac{\epsilon^2}{\cos^2\theta\sqrt{\epsilon^2\sin^2\theta+\omega^2\cos^2\theta}}+\frac{(\omega^2-\epsilon^2)+(\epsilon^2-\omega^2)\sin^2\theta}{\sqrt{\epsilon^2\sin^2\theta+\omega^2\cos^2\theta}}$$

$$=\frac{\epsilon^2}{\cos^2\theta\sqrt{\epsilon^2\sin^2\theta+\omega^2\cos^2\theta}}+\sqrt{\epsilon^2\sin^2\theta+\omega^2\cos^2\theta}-\frac{\epsilon^2}{\sqrt{\epsilon^2\sin^2\theta+\omega^2\cos^2\theta}}$$

Except for a constant factor ϵ^2, the first term of the second member is a function similar to those which occur in our integral. Integrate this equation and divide both members by ϵ^2.

$$\int_0^{\phi}\frac{d\theta}{\cos^2\theta\sqrt{\epsilon^2\sin^2\theta+\omega^2\cos^2\theta}}=\frac{1}{\epsilon^2}\tan\phi\sqrt{\epsilon^2\sin^2\theta+\omega^2\cos^2\theta}+\int_0^{\phi}\frac{d\theta}{\sqrt{\epsilon^2\sin^2\theta+\omega^2\cos^2\theta}}-\frac{1}{\epsilon^2}\int_0^{\phi}\sqrt{\epsilon^2\sin^2\theta+\omega^2\cos^2\theta}\,d\theta.\quad[14]$$

Two cases are to be considered: (1) $\epsilon^2>\omega^2$, (2) $\epsilon^2<\omega^2$. The former will lead to the formula for positive spherulites ($\epsilon>\omega$), the latter corresponds to the case of negative spherulites ($\epsilon<\omega$). They must be treated separately.

2. *Application to negative spherulites* ($\epsilon<\omega$).

Following Legendre's notations, we write

$$c^2=\frac{\omega^2-\epsilon^2}{\omega^2}.$$

Substituting in [14] multiplied by $\epsilon\,\omega \cos\phi$, we get

$$\epsilon\,\omega \cos\phi \int_0^\phi \frac{d\theta}{\cos\phi\sqrt{\epsilon^2\sin^2\theta+\omega^2\cos^2\theta}} = \frac{\omega^2}{\epsilon}\sin\phi\sqrt{1-c^2\sin^2\phi}$$

$$+\epsilon\cos\phi\int_0^\phi\frac{d\theta}{\sqrt{1-c^2\sin^2\theta}} - \frac{\omega^2}{\epsilon}\cos\phi\int_0^\phi\sqrt{1-c^2\sin^2\theta\,d\theta}.$$

Subtracting now from $\omega\sin\phi$ (cp. eq. 7) and using the abbreviation $\Delta(\theta)=\sqrt{1-c^2\sin^2\theta}$, we get

$$\frac{R}{2r} = \omega\sin\phi - \frac{\omega^2}{\epsilon}\Delta(\phi)\sin\phi - \epsilon\cos\phi\int_0^\phi\frac{d\theta}{\Delta(\theta)}$$

$$+\frac{\omega^2}{\epsilon}\cos\phi\int_0^\phi\Delta(\theta)\,d\theta,$$

which may be written

$$\frac{R}{2r} = -\frac{\epsilon}{\omega}\sin\phi\left(\sqrt{\epsilon^2\sin^2\theta+\omega^2\cos^2\theta}-\epsilon\right) - \epsilon\cos\phi\,F(\phi)$$

$$+\frac{\omega^2}{\epsilon}\cos\phi\,E(\phi). \qquad [15]$$

The last two integrals, designated $F(\phi)$ and $E(\phi)$ by Legendre, are known as the *elliptic integrals of the first and second class* respectively; c, which must always be positive and less than unity, is called the *modulus;* ϕ, the *amplitude.*

Remark.

The form of the expression [15] may be further simplified by introducing the function

$$\Gamma = \Delta(\phi)\tan\phi + \frac{\epsilon^2}{\omega^2}F(\phi) - E(\phi),$$

equal to the length of an arc of a hyperbola in which the real semi-axis is equal to the modulus c and the distance from the center to the focus is unity; so that $\frac{\epsilon}{\omega}$ is the value of the conjugate semi-axis.

Substituting, we get

$$\frac{R}{2r} = \omega\sin\phi - \frac{\omega^2}{\epsilon}\Gamma\cos\phi. \qquad [16]$$

3. *Application to positive spherulites* ($\epsilon > \omega$).

Let

$$c^2 = \frac{\epsilon^2 - \omega^2}{\epsilon^2}.$$

Substituting in equation [14] multiplied [redacted] $\epsilon\omega \cos\phi$, we get

$$\epsilon\omega\cos\phi\int_0^\phi \frac{d\theta}{\cos^2\theta\sqrt{\epsilon^2\sin^2\theta+\omega^2\cos^2\theta}} = \omega\sin\phi\sqrt{1-c^2\cos^2\phi}$$
$$+\omega\cos\phi\int_0^\phi \frac{d\theta}{\sqrt{1-c^2\cos^2\theta}} - \omega\cos\phi\int_0^\phi \sqrt{1-c^2\cos^2\theta}\,d\theta. \quad [17]$$

Replacing θ by $\frac{\pi}{2}-\theta$, it is easy to see that

$$\int_0^\phi \frac{d\theta}{\sqrt{1-c^2\cos^2\theta}} = \int_{\frac{\pi}{2}-\phi}^{\frac{\pi}{2}} \frac{d\theta}{\sqrt{1-c^2\sin^2\theta}} = \int_0^{\frac{\pi}{2}} - \int_0^{\frac{\pi}{2}-\phi}.$$

Similarly:

$$\int_0^\phi \sqrt{1-c^2\cos^2\theta}\,d\theta = \int_{\frac{\pi}{2}-\phi}^{\frac{\pi}{2}} \sqrt{1-c^2\sin^2\theta}\,d\theta = \int_0^{\frac{\pi}{2}} - \int_0^{\frac{\pi}{2}-\phi}.$$

Let $\psi = \frac{\pi}{2} - \phi$. Subtracting $\omega\sin\phi$ from [17], we get

$$\frac{R}{2r} = -\omega\sin\phi + \omega\sin\phi\sqrt{1-c^2\sin^2\psi}$$
$$+\omega\cos\phi\left(\int_0^{\frac{\pi}{2}}\frac{d\theta}{\Delta(\theta)} - \int_0^{\frac{\pi}{2}}\Delta(\theta)\,d\theta\right)$$
$$-\alpha\cos\phi\left(\int_0^\psi\frac{d\theta}{\Delta(\theta)} - \int_0^\psi\Delta(\theta)\,d\theta\right).$$

Using Legendre's notations:

$$F_1 = \int_0^{\frac{\pi}{2}}\frac{d\theta}{\Delta(\theta)},\; E_1 = \int_0^{\frac{\pi}{2}}\Delta(\theta)\,d\theta,$$
$$F(\psi) = \int_0^\psi\frac{d\theta}{\Delta(\theta)},\; E(\psi) = \int_0^\psi\Delta(\theta)\,d\theta,$$

the equation assumes the following form:

$$\frac{R}{2r} = +\frac{\omega}{\epsilon} \sin\phi \left(\sqrt{\epsilon^2 \sin^2\phi + \omega^2 \cos^2\phi} - \epsilon\right)$$
$$+ \omega \cos\phi \, (F_1 - E_1) - \omega \cos\phi \left[F\left(\frac{\pi}{2} - \phi\right) - E\left(\frac{\pi}{2} - \phi\right)\right]. \quad [18]$$

The integrals designated F_1 and E_1 are called *complete elliptic integrals of the first and second class* respectively.

4. *Computation of the retardation curve for negative spherulites of strontium carbonate.*

The curve of the ratio $\frac{R}{2r}$ (retardation over diameter) against $\cos\phi$ is constructed by points. Twelve ordinates are computed according to [10], by means of Legendre's tables of elliptic integrals.

The main steps of the computation[15] are as follows:

$$\text{modulus } c = \sin\Theta = \frac{\sqrt{n^2_\gamma - n^2_\alpha}}{n_\gamma} = 0.3076,$$

whence

$$\Theta = 17°55'.$$

Legendre's tables give $F(\phi)$ and $E(\phi)$ for all values of Θ and ϕ from degree to degree. We have interpolated to find the values corresponding to $\Theta = 17°55'$. This interpolation is permissible. The curves $E(\Theta)$, plotted against Θ, for eight values of ϕ (10°, 20°, . . . 80°), have been shown to be very nearly linear functions of Θ. Their slight concavity upwards affects the value of $E(\Theta)$ only in the 5th decimal place and we use four places only in our computations, which is amply sufficient for our purpose. Interpolation for the function $F(\Theta)$ is similarly justified.

APPENDIX II.

COMPARISON OF THE "SPHERULITIC FIGURE" WITH THE INTERFERENCE FIGURE OF A UNIAXIAL CRYSTAL CUT PERPENDICULAR TO THE OPTIC AXIS.

For the sake of simplicity, we shall use here our approximate solution for the curve of $\frac{R}{2r}$ in a spherulite. We shall establish, with similar simplifications, the expression of the retardation in a slice cut from a uniaxial crystal normal to the optic axis and examined in convergent light. Comparison of the two expressions will show that the law of spacing of the rings is different in the two patterns, *"spherulitic figure"* and *interference figure,* which at first sight may look exactly similar.

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[15] Legendre's notation for the modulus is $c = \sin\theta$. We substitute here Θ for θ to avoid confusion with our angle θ defined in Fig. 2 (section IV, 3).

Let us consider a spherulite with a diameter $2r$ equal to unity. Its retardation curve is given by the equation

$$R_1 = \pm (\epsilon - \omega)\, \phi \cos \phi.$$

If we call x the distance, measured from the center of the spherulitic figure, at which the retardation R_1 occurs, we know that

$$x = \cos \phi$$

and the above equation becomes

$$R_1 = \pm (\epsilon - \omega)\, x \operatorname{arc} \cos x. \qquad [12]$$

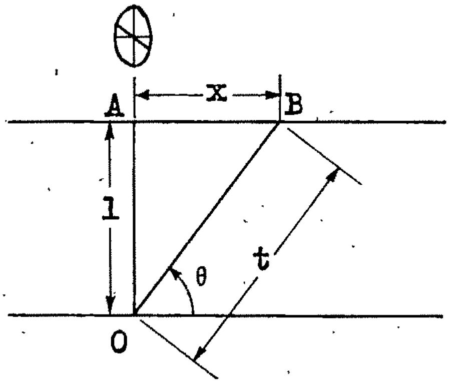

Fig. 6. Cross-section of a slice cut through a uniaxial crystal normal to the optic axis.

Consider now a slice cut in a uniaxial crystal normally to the optic axis, observed in convergent light (Fig. 6). Let θ be the acute angle which a ray of light OB makes with the horizontal AB. The retardation R_2 at a point B, at a distance x from the center A of the interference figure, will be

$$R_2 = (n' - n'') \cdot t.$$

As $x = \cot\theta$, it is easy to see that

$$t = \frac{1}{\sin\theta} = \sqrt{1 + x^2}$$

and (cf. equation 2) that

$$n' - n'' = \pm\,(\omega \sin^2\theta + \epsilon\cos^2\theta - \omega) = \pm\,(\epsilon - \omega)\,\frac{x^2}{1 + x^2},$$

so that the expression of the retardation becomes

$$R_2 = \pm\,(\epsilon - \omega)\,\frac{x^2}{\sqrt{1 + x^2}}. \qquad [13]$$

Equations [12] and [13] are seen to represent entirely different curves.

It can be seen under the microscope, in monochromatic light, that the concentric rings of the spherulitic figure become farther and farther apart outwards, from the center to the region of maximum retardation. A slice cut in calcite normal to the optic axis, on the contrary, will show concentric circles getting closer and closer together outwards.

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LATE WISCONSIN ICE MOVEMENTS IN MASSACHUSETTS.

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Several papers have appeared recently which discuss the movement or lack of movement of the ice sheet which covered New England during the closing stages of the Wisconsin glaciation. Flint, as a result of his studies in Connecticut, has come to the conclusion that recessive moraines do not exist in Connecticut or in Massachusetts west of the Boston Basin; and that the stratified deposits are unaffected by crumpling or contortion caused by readvance of the ice front after these sediments were deposited.[1] Perkins, working in Maine, found evidence of readvance in the form of folded and faulted clays overlaid by till, drumloid forms resting on stratified wash deposits, and an esker over fossiliferous marine clays.[2] Lane has figured and described an overthrust of till on gravel in Cambridge, near the Harvard yard.[3] Alden, reporting on his work in central Massachusetts, mapped a series of recessional moraines indicating successive halts of the ice front during its northward retreat across the state.[4] Studies by the writer in the central Massachusetts area show that recessional moraines of a normal type do not exist and that stagnation occurred before the final dissipation of the ice in this region.[5] Further studies in different parts of the state have, however, shown that the ice, or, at least, limited tongues or lobes of the ice, did make limited readvances in certain areas. One of these movements is so associated with the kame terraces and other stratified deposits of the Nashua valley that its extent and time of occurrence can be definitely fixed.

ICE MOVEMENT IN NASHUA VALLEY.

A detailed study of the glacial deposits of the Nashua valley has resulted in the discovery of only one exposure with definite evidence of ice movement after any part of the region had been uncovered and subject to the deposition of water sorted sediments. This exposure is in a gravel pit on the south side of the road which follows in the valley of a small stream northeast of Lancaster Commons. A layer of boulder-bearing till, four to nine feet thick, overlies sand and coarse gravel. The latter material is well sorted and cross-bedded, and exposed to a depth of 15 feet or more. The contact line between the gravel and till is slightly undulating but the underlying gravels show no evidence of crumpling or disturbance. In all probability they were frozen into a solid mass when the ice moved over them and deposited the layer of till. This till is typical boulder-bearing material with numerous boulders of various sizes scattered through it. Some of these boulders are four or five feet in diameter (Fig. 1).

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[1] R. F. Flint, Geol. and Nat. Hist. Survey Conn., Bull. 47, 58, 1930.

[2] E. H. Perkins, Bull. Geol. Soc. Am., 42, 198, 1931.

[3] A. C. Lane, Geol. Mag., vol. 65, 8-11, 1928.

[4] W. C. Alden, U. S. G. S. Bull. 760, 45-47, 1925.

[5] T. C. Brown, this Journal, 19, 359-367, 1930; Bull. Geol. Soc. Am., 42, 467-480, 1931.

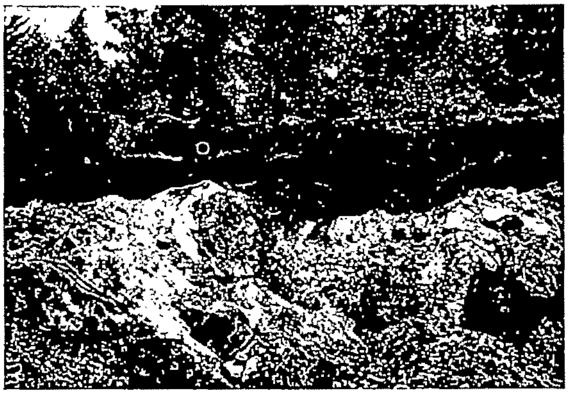

Fig. 1. Excavation in gravel pit 1½ miles northeast of Lancaster Common, showing the darker till overlying stratified sands and gravels. The boulders in the foreground came from the till.

The sands and gravels in this pit are part of the 400 foot kame terrace which is well developed and clearly shown on the Marlboro quadrangle by the 400 foot contour line directly north of this gravel pit. Kame and marginal lake terraces at this elevation are well developed near Clinton and around the Wachusett reservoir in the valley of the South Nashua. Similar terraces at the same or slightly higher elevation are extensively developed in the North Nashua valley. These extend almost continuously from the area north of Whittemore Hill west and north along the side of the valley to Fitchburg and then down the west side of the valley through Leominster to Gates Crossing. These terraces rise to 420 feet in Leominster and South Fitchburg and they are still higher in the northern part of Baker Brook valley.

Terraces at 400 feet elevation do not occur in the main valley of the Nashua north of Still River or in any of the tributary valleys which enter the river north of this point.

An excavation and road cut where the North Lancaster-Bolton road ascends the steep grade one mile east of the Nashua River exposes a fine section of the kame terrace and makes apparent the conditions prevailing here while the sediments were being deposited. At the base of the excavation near the road we find gravelly till; above this comes several feet of finely laminated or varved clay and fine silty sand dipping toward the valley at an angle of 5 to 10 degrees. This is covered by a considerable thickness of fine sand with the beds dipping toward the valley at an angle of nearly 30 degrees. In the road cut near the top of the hill some of the fine sand beds show crumpling as if shoved against the valley wall by ice movement.

In these fine sands are a few small scattered boulders and a few stray masses of till. These boulders and chunks of till were quite evidently dropped into the sand during deposition from masses of floating ice because the thin layers under them are crushed and distorted and the overlying layers arch up over them.

In view of these facts we must conclude that the mass or tongue of ice which occupied the main valley of the Nashua while the 400-420 foot terraces were being deposited did move forward a small amount after these terraces had attained practically their present size and height. This movement did not affect the ice in the North Nashua valley because that ice was already stagnant. Evidence of this is found in the kames and terraces of this valley which show fresh undisturbed ice contact slopes facing toward the valley at all places.

Moreover, this ice movement was very short and insignificant, and the ice masses of the main valley and all of its tributaries became stagnant immediately after the deposition of the 400 foot kames and terraces, and remained so until these ice masses were completely dissipated, for the next lower terrace, ranging in elevation from 370 feet in the South Nashua valley to 390 in the North Nashua and Squanacook valleys, can be traced almost continuously around all of the tributary valleys from Clinton on the south to the New Hampshire line on the north. Not only did the ice become stagnant but it also became crevassed at many places, particularly where ridges or knobs of bed rock jutted up from the valley floor. These crevasses were enlarged and in some places formed channels for the streams which conveyed the regional drainage and gave rise to eskers; in other places they were enlarged still more and gave rise to areas of deposition well out toward the middle of the ice-filled valley. Although changes of this kind took place throughout the valley, the record of these changes is particularly well preserved in the area near Ayer.

TERRACES AND SAND PLAINS NEAR AYER.

Figure 2 shows a portion of the Groton quadrangle in the vicinity of Ayer with the various sand plains, terraces and other surface rocks indicated by appropriate symbols. This map includes an area 5 miles wide and 7½ miles long. The southern limit of this area is 4 miles north of the outcrop shown in Fig. 1. When that readvance took place this whole area was covered with ice except possibly that part occupied by the 400 foot terrace in the southwestern corner. During the deposition of the 400 foot terrace and the succeeding 370-390 foot terraces the drainage of this whole valley system was toward the south through an outlet near Clinton. After this outlet was abandoned a new outlet was opened past Ayer but the level of the water in the valley did not drop at once from the 370 foot level to the 240 foot level as described by Crosby and Alden.[6] Instead, the water made several successive drops of 20 to 40 feet each, and we find kames, terraces, and sand plains built out at these different levels. The cols or outlets controlling these various levels are situated beyond the limits of the Groton quadrangle and have not been located. The nature and distribution of the deposits laid down during these various stages of water level are such, however, that they proved beyond question that the valley was almost completely filled with stagnant ice. Ice which was high enough to retain this water covered the land surface east of this region because many of these sand plains are higher than any land barrier between here and the Atlantic coast.

The highest of these successive stages shown on the accompanying map is the 320 foot level. A single kame at this elevation juts out into the valley southeast of the State Industrial School in Shirley(marked Shaker Village on the map). A large area of sand plain at the same elevation surrounds protruding masses of rock and till in the central part of the Camp

[6] W. O. Crosby, Tech. Quart., 12, 318-324, 1899. W. C. Alden, U. S. G. S. Bull. 760, 72-73, 1925.

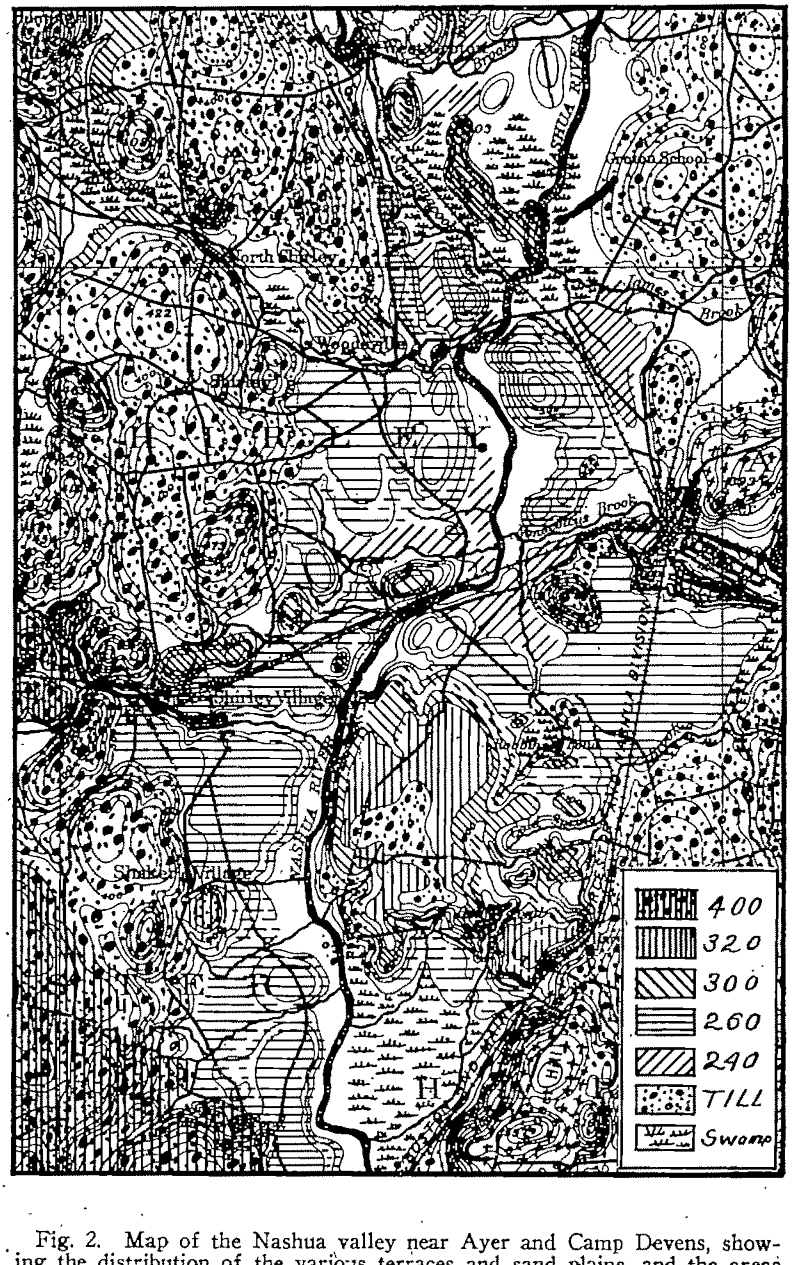

Fig. 2. Map of the Nashua valley near Ayer and Camp Devens, showing the distribution of the various terraces and sand plains, and the areas mantled by till or covered by swamps.

Devens grounds. This area is located in the middle of the valley with ice contact slopes on all sides and lower terraces or till covered ground at much lower elevations all around it. Another extensive area of terraces and plains at the same elevation occurs in the Squanacook valley between Townsend and West Townsend, 10 miles northwest of Camp Devens and beyond the limit of the map.

The 300 foot level shows similar characters developed to a still greater extent. At the northern end of the area is a beautifully developed esker nearly a mile long. The crest of this esker rises to 300 feet and the internal structure, visible in a huge gravel pit at West Groton, shows that it was developed in an open channel in ice and that the margins slumped to their present form after the ice melted away. A mass of rock jutting up in the center of the esker was probably responsible for the crevass in which the esker developed.

In the angle between the two rivers near the junction of the Squanacook and Nashua is a sand plain, level on top, with ice contact slopes in all directions, the whole plain almost completely surrounded by swamp land. This, too, must have accumulated in a widening crevass in a mass of stagnant ice.

Kames and terraces at this 300 foot elevation surround the North Nashua, Mulpus Brook, and Squanacook valleys. A broad level sand plain at this elevation occupies the middle of the valley east of Lancaster. A more or less continuous terrace surrounds the higher plain in the central part of Camp Devens, and a similar terrace forms a prominent feature in the northern part of Shirley Village.

The 260 foot level embraces still more extensive terraces and plains. This level as it is indicated on the map really includes three distinct sets of terraces about ten feet apart in elevation, ranging from 260 to 280 feet. It is impossible to differentiate the different levels on a map of this scale, so they are all mapped as a unit. These plains and terraces exhibit the same features as the higher beds, differing only in that they are more extensive in development and more widespread in distribution. Particular attention is called to the broad level plains which are located near the middle of the valley completely surrounded by lower land. One of these is seen south of the Squanacook, near its junction with the Nashua; another much larger plain occupies the greater part of the area surrounded by the railroad, Nonacoicus Brook and the Nashua, northwest of Ayer. These plains are partially surrounded by lower terraces, represented by the 220-240 levels on the map.

Another noteworthy feature in this area is the extensive development of swamp land near the river, free from all deposits of water-born sediments, and underlain by typical boulder-bearing ground moraine. One of these swamp areas is located in Harvard, between the railroad and the river; the other, as previously mentioned, surrounds the 300-foot sand plain at the river junction in Groton. These areas must have held masses of ice until all terrace and sand plain deposition ceased. No other explanation can account for the total lack of sediments or for the ice contact phenomena facing toward the swamps.

Thus we see that although a slight readvance of the ice took place after the deposition of the 400 foot terrace, the valley masses became stagnant thereafter and melted away in place, some of these even remaining until all deposition ceased and the river assumed practically its present course and gradient. Another fact worthy of note is that these terraces and plains show little or no postglacial uplift or tilting. If there is any tilting at all, it probably does not exceed one or two feet per mile.

CONCLUSIONS.

The outcrops described in this paper furnish conclusive evidence that limited areas of ice in Massachusetts did advance after considerable amounts of sand had been deposited in the form of kame terraces and sand plains. These readvances were evidently insignificant in amount and short lived in duration, if we may base our conclusions on the conditions which prevailed in the Nashua valley. Post-glacial uplift and tilting of the kame terraces, sand plains, and other lake beds in central Massachusetts is much less than that which has been described for other regions to the north and west. The maximum tilting shown here does not seem to exceed two feet per mile. Some of the later and lower terraces do not show any tilting. If this is true how can we harmonize the conditions which prevailed here with those which have been described for the states north of this region and in Canada where the tilting is said to amount to six feet or more per mile? Either the ice vanished from the northern regions first as suggested by Flint, and the uplift antedates the deposition of these horizontal sands and gravels of Massachusetts, or the evidence of tilt is erroneous in that it is based upon the correlation of terraces that are closely adjacent but not contemporaneous.

FITCHBURG, MASS.

SCIENTIFIC INTELLIGENCE.

PHYSICS.

On the Contact of Smooth Surfaces:—In recent years a number of experiments have shown that if an optically smooth plate is lowered onto a similarly polished plate in air, the two surfaces do not come into contact. The top plate remains floating at a distance which is equal to a thickness of several thousand molecules above the bottom plate. Thus Hardy and Nottage found that the end of a polished cylinder, placed on a steel plate, remained at a distance of 4μ above the plate in clean dry air. If pressure was applied to the cylinder it could be forced closer to the surface but on release of the pressure it returned to the former distance. This height remained constant and was the same for glass on glass, or steel on steel. When the air was replaced by such substances as octane, caprylic acid, or octyl alcohol, the separation remained remarkably constant at 4μ. When a trace of palmitic acid was introduced the distance was decreased to 2.3μ.

Watson and Menon using an electrical capacity method similarly found that the distance between polished silver, or polished steel plates, immersed either in air or oil, was still approximately 4μ. It was of course possible that the top plate was supported on solid particles but this view was rejected on the experimental evidence in favor of support by a film of air. To explain this, one would have to assume that there existed between the plates, oriented chains of molecules extending to a distance of several thousand molecules. This is contrary to most physical evidence which indicates that although the first molecular layer of a gas may be oriented and strongly held by the surface, this degree of orientation rapidly diminishes and becomes inappreciable at the distance of a few molecular diameters from the surface.

This subject has now been reinvestigated by S. H. BASTOW and F. P. BOWDEN, who reach the conclusion that the floating above mentioned, was due to dust particles coming between the plates. They arranged two plates so that the upper one could be delicately lowered upon the bottom one in a vessel from which the air could be exhausted, or air, vapors, or liquids admitted. When the plates were in position, they were illuminated by a powerful lamp so placed that interference fringes were obtained by reflection. The utmost pains was exercised to free the air and the liquids from dust particles. When the upper plate was gradually lowered interference fringes in sodium light became visible at a separation of 10μ, and as the lowering continued the fringes broadened and increased in number, until finally colored fringes appeared in white light. As colored fringes are not visible in air films over 2μ in thickness the plates were now closer than this. When the plate finally came to rest under its own weight the plates were separated by a mean distance of 0.45μ. They had not "seized" and the experiment could be repeated indefinitely, the plate always sinking to the same level. The top plate was now raised and the cylinder evacuated to 10^{-5} mm. The interference fringes passed through the same stages and the final equilibrium position was identical with that observed in air. The experiment was repeated several times in vacuo and with air at 0.3 mm. pressure and at 10 cm. pressure. The plate always sank to the equilibrium distance and this distance was not increased as the pressure rose.

If it were possible for chains of polarized molecules to extend to considerable distances from a surface one would expect to find them more readily in a highly polarized substance such as alcohol or water. Experiments were tried with alcohol vapor, nitro-ethane vapor, and water vapor, but the plate again took up its minimum position of 0.4μ.

The plates were now completely immersed in alcohol and the upper plate sank to a distance of about 0.75μ. When a 100 gm. weight was placed on the top plate the minimum separation was reduced to 0.25μ. On removing the weight there was no shift in the fringes and the top plate did not rise.

From these experiments the conclusion is drawn that when a finely polished plate is lowered onto another in air or a liquid the top plate will sink until the two surfaces are in close contact. The apparent floating at a height of 4μ is due to dust or particles between the plates. *Proc. Roy Soc.* A 134, 404, 1931. F. E. B.

The New Conceptions of Matter; by C. C. DARWIN. Pp. xi, 222; frontispiece, 5 pls., 46 figs. New York, 1931 (The Macmillan Company, $3.00).—It is certainly a weird situation in which the physicist finds himself at the present time. Half of the time he is to regard the electron as a particle, and half of the time as a wave packet, but he must never consider an electron as a particle and a wave at the same time. To make the situation worse, even, he is asked to regard the waves as something which is going on nothing, to consider vibrations in which there is nothing to vibrate.

The present book is a very sincere and withal successful attempt by the author to explain in semi-popular language the two half worlds, namely, the particle aspect and the wave aspect of matter. Beginning with the simplest conception of matter as constructed from electrons and protons he describes very clearly the subject of waves and the diffraction of matter. He then takes up the uncertainty principle, polarization, collisions and the exclusion principle.

It is a book that will repay a careful reading. F. E. B.

Molecular Rays; by RONALD G. J. FRAZER. Pp. xii, 204; 7 pls., 78 figures. New York and Cambridge, 1931 (The Macmillan Company, $3.75).—Suppose a tube divided into three compartments, A, B, C, by a diaphragm *ab* and *bc* which are each pierced by a small central hole. Let A be filled with a gas at a pressure not too high and B and C be evacuated. Then those molecules which happen to approach the dividing wall, *ab*, at the aperture, will fly out into the space B, radiating from the aperture. A small number of these will strike the aperture in *bc*, proceed in a small expanding cone and form what is called a molecular beam, or ray. This ray finally strikes the end of the tube where it is detected by some suitable device.

The method was first used by Dunoyer in 1911 to verify the fundamental postulates of the gas kinetic theory. From this beginning an elaborate and important technique has been developed in a direct investigation of the properties of individual molecules. It is this method and its important applications which form the subject of the book. Chapter 1 deals with the production and measurement of molecular rays in considerable detail. The author then takes up the direct measurement of molecular velocities, the scattering and condensation of molecules at solid surfaces, the measurement of magnetic and electric moments, methods for the study of molecular dissociation, and the wave properties of molecules.

The author has presented a most interesting and instructive narrative of the accomplishments in this field, down to the end of 1930, and one which will appeal to all who are interested in the molecular properties of substances. F. E. B.

Operational Methods in Mathematical Physics; by HAROLD JEFFREYS. Pp. viii, 119. London, 1931 (Cambridge University Press, 6s., 6d.; The Macmillan Co., $2.25).—This is the second edition of No. 23 of the Cambridge Mathematical Tracts. After two introductory chapters the author takes up various physical applications, wave motion, conduction of heat, dispersion, and Bessel's functions. It is a book of considerable interest to students of mathematical physics. F. E. B.

Ergebnisse der exakten Naturwissenschaften, Band X. Pp. 452, 118 figs. Berlin, 1931 (Julius Springer, RM. 36, 37.50 bound).—This volume contains the following articles which are issued in separate pamphlets:

Die veränderlichen Sterne; by P. TEN BRUGGENCATE. Pp. 1-83, 30 figs.—The author has collected together the latest information on the period-luminosity and the period-spectral curves, and given a full discussion of the facts and the appropriate theories concerning the cepheids, the long period and the irregular variables.

Interferometry Methods in Astronomy; by F. G. PEASE. Pp. 84-96, 9 figs.—This pamphlet contains a very much condensed account of the Michelson 20 ft. interferometer. The description may be clear to an expert but the layman will have difficulty in following it.

Die neue Feldtheorie Einsteins; by CORNEL LANCZOS. Pp. 97-132.—This contains an extension of Riemann's geometry and a discussion of parallelism at remote distances.

Die dynamische Theorie der Röntgenstrahlinterferenzen in neuer Form; by M. v. LAUE. Pp. 133-158, 4 figs.—The author using almost exclusively Ewald's geometric discussion has sought to bring the theory into a more easily understandable form.

Kerr Effekt, Lichtstrenung und Molekülbau; by H. A. STUART. Pp. 159-206, 12 figs.—By the help of the Kerr effect we may determine the optical polarization ellipsoid which in turn measures the optical anisotropy of a molecule and consequently the electrical moment, which is a far wider constant of the molecule. From the optical symmetrical properties the geometrical structure of the molecule may be determined and also the question of the valence angle and its freedom of rotation derived. This essay gives a résumé of the present knowledge of these questions.

Die prädissosiation und verwandte Erscheinungen; by GERHARD HERZBERG. Pp. 207-284, 22 figs.—Within the last few years the investigation and significance of diffuse band spectra has made considerable progress. It has thereby been shown that they stand in close connection with known chemical processes and provide methods of determination of heats of dissociation, which are of significance for chemistry. Just here is the connection between spectroscopy and chemistry of especial significance. This essay endeavors to present the present state of the development of these diffuse band spectra and to point out the connection with the related phenomena of band spectroscopy.

Die Lichtausbeute bei Stossanregung; by W. HANLE and K. LARCHE. Pp. 285-324, 16 figs.—When electrons and ions, the carriers of electricity, collide with atoms and molecules in their passage through a gas, the latter may be excited or ionized, and in both processes emission of light may result. Part of the light emitted will result from the electron impact and part from the ion impact. There is a third possibility of excitation with light emission, if an atom, excited but not radiating, strikes another atom. The former may give up its energy of excitation and consequently give out light. This process is called impact of the second sort.

Although these three processes have been long known, not much has been found out as to the partition of light among these three processes. This essay seeks to study this sharing of the light under the simplest relations and to apply the result to the more complicated cases. The author has sought to review the most important work in this field and to collect the known results as far as is possible to-day.

Röntgenforschung in der Metallkunde; by ULRICH DEHLINGER. Pp. 325-386, 23 figs.—The discovery of Röntgen-ray interference, produced by the space lattice of crystals, has permitted one to trace the structure of solid bodies down to their building elements, viz. atoms and electrons. From this has grown up two new problems, that of determining the atomic construction planes of particular metals and alloys by measurement with the aid of Röntgen rays, and secondly, the investigation for a determined plan of construction, of characteristic physical and chemical properties.

This essay has well covered the subjects of the structure and properties of the elementary metals, mixed crystals, and metallic compounds, and also the intermediate states of metallic transformations (Unwandlungen), growth textures, corrosion layers, and recrystallization textures.

Chemische Bindung und Quantenmechanik; by MAX BORN. Pp. 387-444, 2 figs. Formerly the problem of valences was fairly well explained on the assumption of saturated forces acting in pairs but the more recent ideas of polar and non-polar union, of shared electrons, and spinning atoms, has required an entirely new mode of attack.

In this paper the author with the aid of considerable abstruse mathematics has shown with considerable success what can be done by the application of the quantum theory to valence problems.

F. E. B.

GEOLOGY AND MINERALOGY.

The Age of the Earth (Physics of the Earth—IV); by ADOLPH KNOPF, CHARLES SCHUCHERT, A. F. KOVARIK, ARTHUR HOLMES, and E. W. BROWN. Pp. v, 487. Bulletin No. 80 of the National Research Council, Washington, D. C., 1931. Paper $4.50, cloth $5.00.—This timely volume gives an up-to-date discussion and evaluation of the various methods that have been used to estimate the length of geologic time. Adolph Knopf, editor of the book, gives an advance summary of the principal results. The separate contributions are as follows:

Geochronology, or the Age of the Earth on the Basis of Sediments and Life; by Charles Schuchert.

Age of the Ocean; by Adolph Knopf.

Calculating the Age of Minerals from Radioactive Data and Principles; by A. F. Kovarik.

Radioactivity and Geologic Time; by Arthur Holmes.

The Age of the Earth from Astronomical Data; by Ernest W. Brown.

Schuchert finds that the maximum thickness of strata in North America formed since the beginning of the Cambrian period is 259,000 feet. He concludes that a mean rate of deposition can not be determined, and that therefore the sedimentary sections can not be translated satisfactorily into years, although there is no great difficulty in harmonizing the sedimentary record with the evidence from radioactivity. An incidental and rather startling conclusion from Schuchert's study is that the rate of sedimentation has increased steadily since early Paleozoic time; during the Cenozoic era sediments accumulated nearly twice as fast as in the Mesozoic, and about four times as fast as in the Paleozoic.

Knopf rejects estimates of geologic time based on the sodium content of the ocean, because several uncertain factors are involved. There is no way to determine the amount of sodium in the primeval ocean; the annual increment probably has varied widely during geologic time; and possibly large quantities of sodium have been removed from the ocean by adsorption at the bottom. The last suggestion would explain how it is that sea water has remained neutral although the sodium and the chlorine are derived from independent sources.

Kovarik and Holmes devote their attention to the methods of age determination based on disintegration of radioactive elements in minerals. An accurate formula developed by Kovarik eliminates the possibility of error due to any common lead that may have been initially present. The greatest age so far determined—1852 million years—is given by uraninite from Carelia, Russia. The values obtained by Kovarik's formula are used by Holmes, who treats exhaustively many aspects of radioactivity as applied to geologic problems. His paper, with its extensive bibliographic lists, is a reference work of especial value to geologists.

E. W. Brown, in the final section of the book, concludes that at the present time the age of the Earth can not be estimated from astronomical data alone, but that the estimate from radioactivity is acceptable to astronomers. CHESTER R. LONGWELL.

Upper Devonian Vertebrates from East Greenland; by ERIK A: SON STENSIÖ. Meddel. om Grønland, Bd. **86**, No. 1, pp. 212, 36 pls., 95 t. figs., 1931.—During his expeditions to East Greenland, Doctor Lauge Koch collected from the Upper Devonian strata of central East Greenland a large number of fish remains (ostracoderms of old). To get at the internal structures of the head, a great deal of labor was necessary to remove the hard rock, and this was done by Mrs. Stensiö and Miss A. Brasch, under a binocular microscope with the specimens submerged under refracting fluids. As the Greenland material consists largely of separated bones, it was further necessary to study the better specimens from Gaspé (*Bothriolepis canadensis*) and from Scotland (*Pterichthyodes milleri*). The result is a great mass of morphologic detail (pp. 27-159), such as we are now accustomed to expect of Doctor Stensiö. The Greenland material itself, described on pages 160 to 207, consists of *Bothriolepis* (2 species, 1 new), *Remigolepis* n. gen., with 6 named species (5 new), some unnamed arthrodiran material, *Holopthychius* in 2 species, and other indeterminate specimens.

Stensiö classifies the Pisces into the divisions Elasmobranchii and Teleostomi. The former has the subclasses Acanthodii (their systematic position is uncertain but they appear to be "allied to the Arthrodires and the Antiarchi"), Placodermi (with the orders Arthrodira and Antiarchi), Holocephali, and Selachii. The order Antiarchi has the families Remigolepidae (only genus *Remigolepis*) and Asterolepidae with the three subfamilies Asterolepinae (*Asterolepis, Pterichthyodes*), Microbrachiinae (*Microbrachius*), and Bothriolepinae (*Bothriolepis*). The genus *Cypholepis* is unplaced.

C. S.

The Geology of the Glass Mountains, Texas. Part I, Descriptive Geology; by PHILIP B. KING. Univ. Texas Bull. No. 3038, pp. 167, 6 pls., 43 t. figs., 1930 (1931). *Part II, Faunal Summary and Correlation of the Permian Formations with Description of Brachiopoda;* by ROBERT E. KING. Univ. Texas Bull. No. 3042, pp. 245, 44 pls., 5 t. figs., 1930 (1931).—These two very important memoirs on the Permian of southwestern Texas are the result of three entire summers of field work and three academic years spent in the Graduate School at Yale University. The authors have made use of all previously published knowledge and collected their fossils with great care as to their correct location in all the sections. Moreover, they have not restricted themselves wholly to the Glass Mountains but have seen the Permian throughout Texas, and have compared their fossils with those of other localities in western and arctic North America, the Andes, Mexico, western Russia, and India. The object of all this labor was to make the Marathon region of west Texas the type area for international correlations of the Permian, since here, as nowhere else, there are 6,000 feet of marine deposits of this system, overlying an equally thick series of Pennsylvanian formations. Fusulinids, ammonites, and diagnostic brachiopods abound throughout these two systems, though not all of them are yet described. All in all, the work does the authors and the Texas Geological Survey great credit, and we congratulate them on their praiseworthy results.

The Glass Mountains are of the Marathon Basin of southwestern Texas and lie shortly to the east of the Cordillera of western North America. Early in Cenozoic time the Marathon region was broadly domed and slightly folded due to the late movements of the Laramide Revolution. Then the Cretaceous, less than 1,500 feet thick, was stripped from the top of the dome by the aerial forces, and the erosion also penetrated deeply into the older Paleozoic formations. Here, therefore, there is to be seen, as it were, through a large open window in the Cretaceous plateau, a long history revealing two periods of orogeny, about 7,000 feet of Permian strata, largely limestones and dolomites, 8,000 feet of Carboniferous, 50-300 feet of Devonian novaculite, and over 1,000 feet of Ordovician—truly an amazing record! The clastics of this mighty pile of sediments have very largely come from the old borderland of Llanoria which lay immediately to the south and east.

These strata and their structure are described and mapped in detail by Philip King, and the stratigraphy established with the aid of Robert King, who identified the fossils collected and made a detailed study of the brachiopods. The Permian is unconformably overlain by the Lower Cretaceous and the same unconformable relation is true for the Upper Carboniferous below. The break above is due to very late Permian deformation, when "the rocks were tilted to the northwest and folded into low domes and anticlines" (p. 127). The unconformity below, however, is very marked, and is due to the Caballos orogeny, a crustal deformation occurring throughout Texas and Arkansas. This Caballos deformation was in three overlapping stages: (1) an epoch of folding while the sea remained in the area depositing the later Gaptank formation; (2) an epoch of overthrusting with the overthrusts cutting across the folds to the extent of at least 5 miles; and (3) an epoch of cross-warping, which deformed both folds and thrusts. The author concludes "that the folding epoch was initiated in early Gaptank time, and continued until near the end of the Gaptank, and that the last two epochs took place late in the Pennsylvanian, and before Permian time" (p. 110). This orogeny is but a part of the Hercynian folding that raised above sea-level the entire eastern half of the Ouachita geosyncline, converting it into land, over which the later Permian epeiric sea transgressed.

During early Mesozoic time the Marathon region was peneplaned and later on covered by the Lower and Upper Cretaceous deposits. Then came the Laramide Revolution which is recorded in two phases: "The first, immediately following the latest Cretaceous, produced the mountains of northern Mexico and southwestern Trans-Pecos Texas." It was at this time that the Marathon dome was made. "The second phase, which is post-Eocene, resulted in the moderate folding of early Tertiary lavas." Finally, near the close of Pliocene time, "the Glass Mountains area was cut by a system of normal faults, which cross the folds" (127).

The bulk of Robert King's memoir is taken up with the description of the Permian brachiopods of the Glass Mountains (pp. 42-133), which total 185 forms (74 new) in 47 genera (4 new: *Parenteletes, Orthotetella, Prorichthofenia, Uncinuloides*), and of these 158 are restricted to Permian formations, the remainder coming upward from the older Pennsylvanian. With these specific results, the author is prepared to take up interregional correlations throughout the Cordillera of North America (pp. 6-42). Finally, all his results are synchronized in a Correlation Chart.

The 185 brachiopods occur in the formations as follows:

		Spp.	Restricted	From below
Capitan (above) ls. and dol., 3,000 feet thick		12	0	12
Word formation, 1,500 feet thick		78	25	42
Leonard " 2,100 feet thick	Probably facies of one another	70	9	44
Hess " 1,800 feet thick		54	10	17
Middle and upper Wolfcamp	50-700 feet thick	45	6	29
Lower Wolfcamp		34	0	22

The lower Wolfcamp is marked by the ammonite zone of *Uddenites.* The brachiopods here are closely allied to those of the Andean "Upper Carboniferous," since 10 species occur in common. There are also linkages with the Trogkofel limestone of the Austrian Alps. While the brachiopods of the lower Wolfcamp include many Pennsylvanian forms, there are many definite heralders of the Permian. It is in the middle Wolfcamp that the characteristic Lower Permian fusulinid *Schwagerina* appears, and in the upper third of this formation the evolutional aspect of the brachiopods becomes decidedly Permian, with the genera *Orthotetella, Scacchinella, Waagenoconcha, Aulosteges, Teguliferina, Parakeyserlingina, Spirifer condor,* etc.; here also occur the ammonites *Perrinites cumminsi* and *Prothalassoceras welleri.*

The Hess formation introduces the additional brachiopod genera *Geyerella, Prorichthofenia,* and the striking *Lyttonia,* while the Leonard has the wide-spread but range-limited *Productus ivesi,* a typical Kaibab and San Andres species. Of *Marginifera* there are 5 forms and of *Aulosteges* 4. Of ammonites there are the characteristic *Perrinites compressus* and *P. vidriensis.* The Leonard correlates definitely with the Kaibab formation of Arizona and the San Andres of New Mexico. It is probable that the Hess and Leonard are but facies of the same time.

The Word formation is marked especially by the ammonites *Waagenoceras dieneri, Medlicottia burckhardti,* and *Stacheoceras bowmani,* and among brachiopods by the large *Lyttonia.* It is interesting to note that it is in the upper Word that many of the brachiopods are related to those of arctic faunas and of the Phosphoria formation of Idaho; this means intercommunication of the seaways.

Finally, it is to be noted that the Capitan is of reef origin and largely dolomitic, and in consequence has so far yielded but small faunas. The common fossil throughout is the fusulinid *Polydiexodina capitanensis.* C. S.

Dalradian Geology: The Dalradian Rocks of Scotland and their Equivalents in Other Countries; by J. W. GREGORY. Pp. 188; with 4 pls., 16 diagrams, and 2 maps. London, 1931 (Methuen & Co.).—According to J. W. Gregory, the Dalradian consists of a group of five series of rocks of Pre-Cambrian age. Their sequence, age, and metamorphism comprise one of the most controverted problems in Scottish geology. In the recently issued Chapters on the Geology of Scotland by Peach and Horne the term Dalradian is hardly discoverable, being but casually referred to as a waste-basket term; in this book it is sought to raise it to world-wide significance. "The Dalradian system of Scotland . . . . corresponds to a world-wide series of stratified schists which is earlier than the Keweenawan and Torridonian, and younger than the coarse gneisses which form the base of the geological column wherever the base is known."

The intercontinental correlations, however, inspire no confidence, for like all such correlations made in the past they are based largely on subjective criteria. The North American correlations are peculiarly in error, such as making the Keewatin the equivalent of the Huronian Bruce and Cobalt formations. No use is made of the method pioneeered by Arthur Holmes, namely to make intercontinental correlations on the basis of ages determined by radioactive evidence, which is the only method so far proposed that from its objective nature can inspire real confidence.

Because of the mass of local detail the book must prove of main interest to British geologists. In general, the ideas of Bailey and of Tilley that inversions, nappes, and slides are important elements in the structural geology of the Highlands is rejected.

ADOLPH KNOPF.

The Microscopic Characters of Artificial Inorganic Solid Substances or Artificial Minerals; by A. N. WINCHELL, with a chapter on the Universal Stage; by R. C. EMMONS. Second edition. Pp. 403; 311 figs., 2 tables, 5 plates in pocket. New York, 1931 (John Wiley and Sons, $5.00).—The present book is an expansion of the valuable work first published 1927 as No. 4 of the University of Wisconsin Studies in Science. By the addition of a section of 150 pages on Principles and Methods, giving the essentials of optical microscopy, with special emphasis on the use of polarized light, the book has been made a self-contained unit. Many unpublished data on the optical properties of certain substances have been incorporated.

A. K.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Sorcerers of Dobu; by R. F. FORTUNE. Pages xxviii, 318; 8 pls., 5 figs. New York, 1932 (E. P. Dutton & Co., $5.00).—The anthropologist who wants reliable first-hand reports of primitive life on Pacific islands will welcome this account of a set of social institutions which have not hitherto been described. He will find an elaborate and painstaking display of the form of mother-right that is called *susu*, a collection of the songs of ritual and mythology, a highly interesting analysis of the romantic inter-island trade called *kula*, vivid details of a sex life that is as prudish as it is obscene, a full description of the magic that is worked in a community where everyone is a sorcerer and believes that nothing in nature—from yams to motherhood—can result from any cause but magic.

For the non-technical reader there are many passages of diverting, or gruesome, or instructive, matter. It is diverting to learn that the yams of Dobu are believed to leave the ground at night and have a good time roaming in the forest, or that no sexual desire can be aroused except by magic. It is gruesome to read of pervasive treachery and unrelenting jealousy, of the fear of poisoned food that "dominates native life." It is instructive to see how close a parallel the author draws between the unreason of Dobu and the unreason of America.

The non-technical reader, however, will find the entertaining passages too few and brief. He will feel that he is plowing through a dozen pages of anthropological minutiae to reach a page that gives him a picture of some phase of life. The arrangement of the material accentuates his feeling, for the first third of the book is largely concerned with the intricacies of *susu*. He will be sorry that technicalities fill so much space, because he could have been so much better instructed if the author had devoted a much larger proportion of his chapters to descriptions that would convey more understanding of the people and their surroundings. An illustration of the author's indifference to description is the fact that he does not tell us where Dobu is, nor how large it is, nor whether it is an atoll or a lofty pile of lava, nor what the "Government" is, nor anything about the missionaries to whom he often refers. Not till three-fourths of the way through the book do we find a chart which discloses to us what the author has been talking about.

This fault-finding is caused by the merits of the book; for we become so enthusiastic about parts of it that we wish the whole might have been planned to maintain our pleasure.

HENSHAW WARD.

The University Series.—The volumes of this Series, as already published and with others to follow, are planned for the intelligent reader who wishes to inform himself in regard to the rapid progress of science as dealing immediately with the life of mankind.

Eight volumes have already been issued. The titles of these give some idea of the scope of the work. The names of the individual authors, also, are a guaranty of their accuracy and interest. The books now complete are as follows:

The Earth; by CHESTER A. REEDS.
The Coming of Man; by GEORGE GRANT MACCURDY.
The Coming and Evolution of Life; by HENRY E. CRAMPTON.

Heredity and Variation; by L. C. DUNN.
The Animal World; by JAMES GEORGE NEEDHAM.
Fossils; by RICHARD SWANN LULL.
The Plant World; by C. STUART GAGER.
Stars and Planets; by DONALD H. MENZEL.

Those interested are referred to the notice of one of these volumes entitled "The Earth"; by Chester A. Reeds on p. 185 of the February (1932) number of the Journal. The remaining seven volumes will be noticed in early numbers.

In addition to these eight books, thirty-two others are planned, which will treat of the history of man: of his mind, morals, and economic interests; also of his contributions to literature and art. The volumes vary from about 100 to 150 pages, are fully illustrated, uniformly and well bound in cloth. The books are sold by subscription; the prices and terms can be obtained from the publishers (The University Society, 468 Fourth Avenue, New York City).

Observatory Publications. The following quarto volumes and pamphlets have been received recently.

YERKES OBSERVATORY OF THE UNIVERSITY OF CHICAGO. Volume VI. *Micrometric Measures of Star Clusters*; by EDWARD E. BARNARD; edited by EDWIN B. FROST, GEORGE VAN BIESBROECK and MARY R. CALVERT. Pp. 106. (The University of Chicago Press, $4.00.)—The Editors have presented in this volume the photographic measurements of many star clusters made by the late Dr. Barnard[1] at the Yerkes Observatory with the 40-inch telescope and chiefly through a yellow glass screen. A few facts of general interest may be mentioned here.

Little was known about these globular clusters prior to the present century, but they have been much studied since then. Dr. Barnard (1906-07) described them as "simply superb" in the "fire and life given by myriads of stars" seen in a powerful (40-inch) telescope, under favorable conditions as to steady air and absence of the moon. The measures made at the date mentioned proved the grandeur of these great masses of stars, the dimensions of the individual members and the distance that separated them. The clusters were found to be not nebulous, while the anticipated relative motion among the stars failed to be established. Some of the clusters were shown to be superimposed on star clouds of the Milky Way, and hence as compared with the latter, they must be relatively near and small.

THE ALLEGHENY OBSERVATORY OF THE UNIVERSITY OF PITTSBURGH. Volume VIII, Nos. 3 and 4. Pp. 37-64. These publications record the observations; by KEIVIN BURNS, astronomer of the Allegheny Observatory, and by Prof. FRANCIS M. WALTERS, JR., of the Carnegie Institute. They give the wave lengths in the spectra of the vacuum copper arc (No. 3, pp. 37, 38) and the same in the spectrum of the vacuum iron arc. (No. 4, pp. 39-64.)

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[1] Dr. Barnard died on February 6, 1923 (this Journal, vol. 5, p. 348).

OBSERVATORY OF THE UNIVERSITY OF MICHIGAN. Volume IV. Nos. 1-4—Pp. 1-73 have been received. The subjects are as follows: No. 1, The Spectrum of Zeta Tauri, by HAZEL MARIE LOSH. No. 2, The radial velocity of Beta Librae, by DEAN B. MCLAUGHLIN. No. 3, The spectral variations of 25 Orionis and 52 π Aquarii. No. 4, Some new methods in astronomical photography, with application to moving pictures of celestial objects; by FRANCIS C. MCMATH, HENRY S. HULBERT, and ROBERT R. MCMATH. Pp. 53-73; 3 figs., 11 pls. Of the plates, Pl. 1 shows the Observatory at Lake Angelus. Plates 2-11 give views of the Pyrex Reflector with details of the apparatus used. No. 5. A study of S α Sagittae. by J. A. ALDRICH. Pp. 75-92. No. 6. A Device for the differential correction of conditioned orbits by Leuschner's method, A. D. MAXWELL, Pp. 93-99.

ROYAL OBSERVATORY, GREENWICH. SIR FRANK DYSON, Director.—1. *Photographic magnitudes of stars brighter than 14.*$^{\text{mo}}$ *in forty of Kapteyn's selected areas.* Pp. 1-69. (Price 6s. 6d.)—The areas included in these observations are as follows: Zone + 15°, areas 68 to 91; Zone + 30°, areas 51-60, 63, 64; Zone + 45°, areas 30, 31, 32; Zone + 600°, area 13. The magnitudes are also given of 395 stars within 1° of the North Pole.

2. *Photo-Heliographic results,* 1929. (15s. 0d.)—Photographs of the sun taken in the year 1929 at Greenwich, at the Cape, and in India. Pp. C i-ix. Also Positions and Areas of Sun Spots and Faculae for each day of 1929. Pp. C 1-C 131.

DOMINION OBSERVATORY, OTTAWA. R. MELDRUM STEWART, Director. Vol. X. *Bibliography of Seismology.* No. 11. July, August, September, 1931; by ERNEST A. HODGSON. Pp. 177-190. Ottawa, 1931 (Price 25 cents).—The titles of one hundred (Nos. 1001-1100) publications are included in this bibliography, in some cases the results are given in abstract. Ten collaborators, who have taken part in the work, include workers in Italy, Java, Japan, and England as well as this country and Canada.—No. 12. October, November, December. Pp. 191-210. Ottawa, 1932 (25 cents).

Hayden Memorial Medal.—The Philadelphia Academy of Natural Sciences has awarded the Hayden Memorial Medal for 1932 to Dr. Reginald A. Daly, Sturgis-Hooper Professor of Geology at Harvard University.

PUBLICATIONS RECENTLY RECEIVED.

Conférences D'Actualités Scientifiques et Industrielles. XIX. La Haute Précision des Mesures de Longeur; by M. A. Pérard. (5 fr.) XX. L'Effet Photo-Electrique Des Rayons X Dans Les Gaz; by Pierre Auger. (5 fr.) XXII. Fluorescence Durée Elémentaire D'Emission Lumineuse; by Francis Perrin. (5 fr.) XXIII. Désintégration Artificielle des Eléments par Bombardement de Rayons Alpha; by Maurice de Broglie. (5 fr.) XXV. Les Applications des Rayons X A L'Etude des Composés Organiques; by M. J.-J. Trillat. (5 fr.) XXVI. L'Etat Liquide et Les Etats Mésomorphes; by M. J.-J. Trillat. (5 fr.) XXVII. Les Systémes Auto-entretenus et Les Oscillations De Relaxation; by Ph. Le Corbeiller. (8 fr.) XXVIII. Le Quartz Piézo-Electrique Ses Applications A La T. S. F.; by F. Bedeau. (5 fr.) XXIX. L'Hydrogéne est un Mélange: ortho et Parahydrogéne; by Eugéne Darmois. (5 fr.) XXX. Les Piles Sensibles A L'Action De La Lumiére Leur Mecanisme et Leurs Applications; by M. Rene Audubert. (8 fr.) Paris, 1931. Librairie Scientifique Hermann et Cie.

Comparative Psychology Monographs. Serial No. 38. Yale Laboratories of Comparative Psychobiology; by Robert M. Yerkes.

Tropical Plant Research Foundation. Scientific Contribution No. 20. The Utilization of Varieties in the Field Control of Sugar Cane Mosaic and Root Diseases in Cuba. (A Preliminary Report); by James A. Faris. No. 21. Some Studies of Root Habits of Sugar Cane in Cuba; by James H. Jensen. New York, 1931.

Arkansas Geological Survey. Information Circular 1: A Barite Deposit in Hot Spring County, Ark. Field Work by Bryan Parks, Text by Bryan Parks with The Assistance of George C. Branner. Little Rock, 1932.

Zoology; by F. E. Chidester. New York, 1932 (D. Van Nostrand Co., $3.75). The Grand Coulee; by J. Harlen Bretz. Special Publication No. 15 (American Geographical Society, $4.00).

Ursprung Der Menschheit. Uber den Engeren Anschluss Des Menschengeschlechts An Die Menschenaffen; by Dr. Hans Weinert. Stuttgart, 1932 (Ferdinand Enke, 21 RM, 23 RM bound).

Index Generalis. Tome 1. Annuaire General Des Universites. Publie sous la Direction de R. de Montessus de Ballore. (Editions Spes, 17 Rue Soufflot, Paris, Ve).

The Universe Unfolding; by Robert H. Baker. Century of Progress Series. Baltimore, Md., 1932 (Williams & Wilkins Co., $1.00).

Principles of Soil Microbiology; by Selman A. Waksman. Second Edition Entirely Revised. Baltimore, Md., 1932 (The Williams & Wilkins Co., $10.00).

Sorcerers of Dobu. The Social Anthropology of the Dobu Islanders of the Western Pacific; by R. F. Fortune with an Introduction by B. Malinowski. New York, 1932 (E. P. Dutton & Co., $5.00).

Concordance de l'arrangement quantique, de base, des électrons planétaires des atomes, avec la classification scalariforme, hélicoidale, des éléments chimiques. Novembre, 1930. Considérations sur la Structure Du Noyau De L'Atome. Décembre, 1929. Charles Janet. (Beauvais Imprimerie Départementale de L'Oise.)

Chemical Analyses of Igneous Rocks, Metamorphic Rocks and Minerals. Compiled from the Records of the Geological Survey by Eileen M. Guppy and contributions by others. London, 1931 (H. M. Stationery Office, Adastral House, Kingsway, London, W. C. 2, 3/6 "postage extra."

The following eight publications are part of the University Series. This Series is sold by subscription by The University Society, 468 Fourth Ave., New York City.

The Earth. Our Ever-Changing Planet. By Chester A. Reeds. Geology.

Heredity and Variation. Continuity and Change in the Living World. By L. C. Dunn. Genetics.

The Plant World. Plant Life of Our Earth. By C. Stuart Gager. Botany.

The Animal World. Animal Life of Our Earth. By James George Needham. Zoology.

Fossils. What They Tell Us of Plants and Animals of the Past. By Richard Swann Lull. Paleontology.

Stars and Planets by Donald H. Menzel. Astronomy.

The Coming and Evolution of Life. How Living Things Have Come to Be As They Are. By Henry E. Crampton. Biology.

The Coming of Man. Preman and Prehistoric Man. By George Grant MacCurdy. Prehistoric Anthropology.

Transactions of the Connecticut Academy of Arts and Sciences. February 1932. Volume 31. The Cephalopods of the Bighorn Formation of the Wind River Mountains of Wyoming; by A. K. Miller. New Haven, Conn.

Carnegie Institution of Washington. Year Book. No. 30. 1931. With Administrative Reports through December 11, 1931. Washington, D. C. 1931.

Smithsonian Institution. United States National Museum. Bulletin 159. The Birds of the Natuna Islands by Harry C. Oberholser. (Price 25 cents. For sale Superintendent of Documents, Washington, D. C.)

Electrical Phenomena in Gases by Karl K. Darrow. Baltimore, 1932 (The Williams & Wilkins Co., $8.00).

Allen's Commercial Organic Analysis. Vol. IX, 5th Edition. The Proteins of Plants, the Proteins of Milk, Milk Products, Meat and Meat Products; by the Editor and the following contributors: C. Jordan Lloyd, G. D. Elsdon, H. Leffmann and John Golding, E. R. Bolton, C. Robert Moulton. Editor C. Ainsworth Mitchell. Philadelphia, 1932 (P. Blakiston's Son & Co., $7.50).

Enzyklopädie der Technischen Chemie. 2 Auflage. Bd. VIII. Natriumverbindungen-Salophen. Berlin, 1932 (Urban & Schwarzenberg, 42.50 Mks. and 50 Mks. bound).

Chemistry in the Service of Man; by Alexander Findlay. Fourth Edition. New York, 1932 (Longmans, Green & Co., $2.50).

Report of the United States National Museum 1931. Smithsonian Institution, Washington, D. C. (Superintendent of Documents, 25 cents).

Smithsonian Institution. United States National Museum. Bulletin 157. The Butterflies of the District of Columbia and Vicinity; by Austin H. Clark. (Superintendent of Documents, $1.50.) Washington, D. C. 1932.

Association Theory of Solution and Inadequacy of Dissociation Theory; by Jitendra N. Rakshit. Calcutta, 1930 (S. C. Auddy & Co.).

Advanced Electrical Measurements. Smythe-Michels. New York, 1932 (D. Van Nostrand Co., $3.00).

Bulletin of the National Research Council. Number 86. Bibliography of Bibliographies on Chemistry and Chemical Technology. Second Supplement 1929-1931. Compiled by Clarence J. West and D. D. Berolzheimer for Research Information Service. (National Research Council of the National Academy of Sciences. Washington, D. C., 1932. Price $1.50.)

General Chemistry by Leon B. Richardson. Revised Edition. Henry Holt and Co., $3.50. New York, 1932.

A Course in Quantitative Analysis; Guy and Skeen. Boston, 1932 (Ginn and Company, $2.00).

Carnegie Institution of Washington. News Service Bulletin. Numbers 27, 28. Measuring Distances in the World of Stars. Part I—The Measuring Rods. Part II—A Flight Through Space. Numbers 29, 30. Reptiles Used in Study of Human Physiology. The Year Book of Carnegie Institution. Washington, D. C.

Field Museum of Natural History, Chicago. Field Museum News. April, 1932.

OBITUARY.

Dr. Louis A. Bauer died suddenly on April 12 at the age of sixty-seven years. He was assistant professor of mathematics and mathematical physics at the University of Cincinnati 1897-99; chief of the department of terrestrial magnetism of the U. S. Coast and Geodetic Survey 1899-1906, and director of this department in the Carnegie Institution from 1904. His contributions to his chosen subject were many and important. The prominence, gained through them, won him a place in many scientific societies at home and abroad.

Dr. Benjamin Kendall Emerson, the veteran geologist, for many years professor at Amherst College, died on April 7 at the age of eighty-eight years. A notice will appear later.

Dr. Albert Perry Brigham, geologist and geographer, died on March 31 at the age of seventy-six years. He became professor of geology at Colgate University in 1902, and was president of the Association of American Geographers in 1914.

Dr. Wilson Alwyn Bentley, fellow of the American Meteorological Society, died on December 23, 1931, at the age of thirty-four years.

Dr. Harvey Monroe Hall, the botanist, staff member of the division of plant biology of the Carnegie Institution of Washington, died on March 11 at the age of fifty-eight years.

Miss Mary Frances Seymour, since 1925 professor of biology at Catawba College, Salisbury, North Carolina, died on March 2.

Mr. Charles Livingston Ball, of Oradell, New Jersey, naturalist and illustrator of books on natural history, died on March 22 at the age of fifty-seven years.

Dr. Wilhelm Ostwald, the distinguished German scientist, died on April 4 at the age of seventy-eight years. A notice will appear in a later number.

Dr. Ernest Howard Griffiths, the distinguished British physicist, formerly principal at the University College of South Wales and Monmouthshire, died on March 3 in his eighty-first year.

Professor Giuseppe Martinelli, a member of the Pontifical Academy of Science, and of the Central Office of Meteorology and Geophysics, in Rome, died recently at the age of fifty-four years.

General Gustave Ferrié, president of the section of electricity and terrestrial magnetism of the National Council of France, died on February 16 in his sixty-fourth year.

Dr. A. A. Jaczewski, director of the Institute of Mycology and Plant Physiology in Leningrad, died on February 12.

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Am. J. Sci., **44**. 249, 1917. The year should be given in every case; this renders a series number unessential.

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AMERICAN JOURNAL OF SCIENCE

JUNE 1932

CHARLES SHELDON HASTINGS

1848-1932

Charles Sheldon Hastings died at the home of his daughter in Greenwich, Conn., on January 31, 1932, after an illness of several months. He was born at Clinton, N. Y., on November 27, 1848, was prepared for college in the Hartford Public Schools, and was graduated from the Sheffield Scientific School in 1870.

Throughout his life he was very much interested in astronomy which he began to study immediately upon graduation. His thesis for the doctor's degree, awarded him in 1873, was upon the "Comparison of the Spectra of the Limb and of the Center of the Sun." He was made an instructor in physics in the Sheffield Scientific School in 1871 and retained this position until 1874, when he went abroad for the study of physics, spending two years at Heidelberg and one year at the Sorbonne. During part of this time, he was a student under both Helmholtz and Kirchhoff. On his return to this country, he was made associate professor of physics at Johns Hopkins University, a position which he retained until 1884 when he was called to be professor of physics in the Sheffield Scientific School. He occupied this chair until his retirement in 1915. He acted for many years as consulting expert with the Brashear Company, and continued in this capacity until the death of MacDowell.

During his student days he overstrained his eyes by too close application, and brought on a condition of myopia which remained with him all his life.

His life-work was devoted to optics, and particularly to the calculation and construction of optical instruments.

The usual formulas for the calculations of lens systems, other than those of the greatest simplicity, are extremely complicated, and where such accuracy is desired as is absolutely requisite for the designing of optical apparatus, the formulas become almost unmanageable. Hastings always maintained that greater simplicity could be attained in the mathematical expressions for optical systems, if the conceptions of rays, radii, and indices of refraction, were replaced by the more natural notions of wave and lens surfaces, and light velocities, the surfaces being characterized by their curvatures, rather than by their radii.

In his hands this method gave very satisfactory results, and he was able by its use to determine the spherical aberration of a lens system, the variation of its focal plane, of its spherical aberration, and of its magnification, with varying wavelength of light, and its astigmatism. In short, he was able to do with a four-place logarithmic table, what elsewhere required a whole bureau of computers. Speaking of tables, it may be remarked that he was always most insistent upon keeping the figures of a calculation within the limits of accuracy of the data. I have often heard him speak in derision of engineers who would take three-figure observations and reduce them with seven-place logarithms. For him, also, the method of least squares was something almost sacrosanct.

The data of his observations were preëminently the indices of refraction of different kinds of glass. For these measurements, he designed and constructed a spectrometer which gave him a very high degree of accuracy. The principal feature of this was a glass plate, 8 inches in diameter, which he divided to single degrees by diamond scratches. The 1st degree, the 91st, the 181st and the 271st were further subdivided to tenths of a degree. The reading microscopes were of high power, 220 diameters, and he was able to set them with a probable error of less than 0.″3. The notable thing about the instrument was the care with which he determined the absolute position of each diameter. He was thus enabled to determine an angle of 60°, with a probable error of a single observation, of less than 2″.

This instrument was in constant use for over forty years, and enabled him to determine indices of refraction, accurately to six decimal figures.

When Hastings began his career, the varieties of glass then known did not permit the production of a truly achromatic combination. On account of the irrationality of dispersion, there was always left an abnoxious secondary spectrum. The debt of American astronomy to Hastings in his design of telescopes and spectroscopes is very great. As the years went on, and new kinds of glass were introduced, he was enabled by the aid of his calculations, and the study of literally hundreds of different specimens of glass, to make improvements in the performance of objectives, and practically rid them of secondary color. Up to his time, telescope makers had virtually to use cut and try methods; Hastings was the first in this country to apply strictly scientific methods to the calculation of the secondary color correction.

One of his notable achievements was the construction of an anastigmatic magnifier that was so successful that its use spread over the whole world.

The largest telescope of his design is the 30-inch objective of the Allegheny Observatory. It is a very perfect glass and used for photographic purposes. Other constructions from his calculations are the 26-inch photographic objective of the Yale Observatory in South Africa, the 24-inch visual objective at the Chabot Observatory at Oakland, Cal., the 18-inch visual refractor at the University of Pennsylvania, a twin doublet of 16-inch aperture at Heidelberg, Germany, a 72-inch reflector at Victoria, B. C., and the 15-inch photographic Loomis coelostat at the Yale Observatory, New Haven. This telescope has a fifty-foot focal length and is the third longest telescope in the world.

Obviously an objective, corrected for photographic use, is of no value for visual purposes and vice versa. Hastings, however, made correcting lenses for transforming visual into photographic refractors and brought the astronomical spectroscope to a very high degree of perfection.

He was also always interested in all optical phenomena. In 1920 he published a general theory of halos, in which he explained all the authenticated features of complex halos, with possibly one or two exceptions (for instance, the very rare elliptical halo within 5° of the moon), on the hypothesis of two kinds of simple ice crystals, elongated hexagonal rods, and hexagonal plates.

His published works number some forty odd pamphlets, and the following three books: *General Physics,* written in collaboration with Frederick E. Beach in 1898; *Light,* published in 1901 as one of the Yale Bicentennial Publications; and *New Methods in Geometrical Optics,* in 1927.

As a lecturer Hastings showed great mastery of his subject, and was always entertaining. To a dull student who once asked him why he didn't make his lectures more interesting, I remember he answered, "I make them as instructive as possible; it is for you to supply the interest."

He was deeply interested and widely read in literature, in art and in architecture. I remember that he once devoted considerable time to studying the notable asymmetries of the cathedral at Pisa, as shown in various photographs. His conclusions were published in the Architectural Review in 1909. He possessed great personal dignity but was uniformly cordial to his familiars. Though his hand was not particularly steady, he possessed a marvelous manual dexterity. Personally he will always be remembered as a courtly gentleman of the old school.

Professor Hastings was a member of the National Academy of Sciences, of the American Physical Society, of the Philosophical Society, a fellow of the American Association for the Advancement of Science, medallist of the Franklin Institute in 1926, Officier de l'Instruction Publique, and a corresponding member of the Societa degli Spectroscopisti.

Frederick E. Beach.

The following is a list of the published writings of C. S. Hastings:

Comparison of the Spectra of the Limb and the Center of the Sun, this Journal, **5**, 369, 1873.
On the Influence of Temperature on the Optical Constants of Glass, Ibid., **15**, 269, 1878.
On Triple Objectives with Complete Color Correction, Ibid., **18**, 42[illegible], 1879.
On Lockyer's "Hypothesis that the so-called elements are compound bodies," Am. Chem. J., **1**, 15, 1880.
Report on the total solar eclipse of July 29, 1878. Washington Observations for 1876, Vol. 23, part II, Appendix III, pp. 153-162, 1880.
A Theory of the Constitution of the Sun, Proc. Am. Acad., **16**, 140, 1881.
A Synopsis of the Scientific Writings of Sir William Herschel; by Edward S. Holden and Charles S. Hastings. Smithsonian Reports for 1880. Washington Government Printing Office, 1881.
On the Color Correction of Double Objectives, this Journal, **23**, 167, 1882.
On the modifications of the spectrum of sodium vapor in a Bunsen flame. Abstracts: Proc. Am. Assoc. Adv. Sci., **31**, 218-220, 1882.
A Note on Triple Objectives, Johns Hopkins Univ. Circular No. 15, May 13, 1882.
Comet Cruls, Sidereal Messenger, **1**, 171, 1882.
Atmosphere of Venus in Transit, Sid. Mess., **1**, 273, 1883.
On the variation of the focal length of an objective with change of temperature, Astron. Nachr., **105**, 69, 1883.
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Recent Experiments in the Construction of Telescope Objectives, Sider. Mess., **1**, 244, 1883; **2**, 39, 1883.
On some recent experiments on the construction of telescope objectives, Johns Hopkins Univ. Circular, **2**, 9, 1883.
The history of twenty-three new double stars; by C. S. Hastings and E. S. Holden, Science, **2**, 66, 1883.

A singular optical phenomenon, Science, 3, 273, 1884.
Inertia, Science, 3, 559, 1884.
On the Law of Double Refraction in Iceland Spar, this Journal, 35, 60, 1888.
A General Method for Determining the Secondary Chromatic Aberration for a Double Telescope Objective, Ibid., 37, 291, 1889.
Physics of Chemistry: Introduction to an Elementary Text Book of Chemistry; by William G. Mixter. Pp. 1-45, 90-94. New York, 1889 (John Wiley and Sons).
The History of the Telescope, Sider. Mess., 10, 335, 1891.
The Ladd Observatory. (Address of C. S. H. on pp. 24-26.) Providence, R. I., 1891.
On Certain New Methods and Results in Optics. Memoirs of the National Acad., 6, 37, 1893.
Report on Specimens of Crown and Flint Glass belonging to the Lick Observatory, Publications of the Lick Observ., 3, 133, 1894.
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Biographic Memoir of James Edward Keeler. Read before the Nat. Acad. Sciences, Apr. 23, 1903. Pp. 233-246. Washington, D. C. (Judd and Detweiler, Printers).
On Errors of Eccentricity in the Human Eye, Am. J. Physiol., 13, 304, 1905.
On the Optical Constants of the Human Eye, this Journal, 19, 205, 1905.
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Simon Newcomb, Ibid., 28, 290, 1909.
Architectural Refinements in Medieval Churches computed, Arch. Review, [illegible]6, 132, 1909.
Biographical Memoir of Josiah Willard Gibbs, Nat. Acad. Sciences Biographical Memoirs, 6, 375, 1909.
Hal[illegible] May 20, 1915, analyzed, Monthly Weather Review, 43, 498, 1915.
Arthur Williams Wright, this Journal, 41, 361, 1916.
A General Theory of Halos, Month. Weather Rev. 48, 322, 1920.
A new type of telescope especially adapted to spectrometers, Jour. Opt. Soc. of Amer., 11, 63, 1925.
New Methods in Geometrical Optics; by Charles S. Hastings. Pp. vi, 103. New York, 1927 (The Macmillan Co.).
The Foucault Pendulum of the Peabody Museum of Yale University, this Journal, 16, 147, 1928.

SOME EOCENE VOLCANICS IN SOUTHEASTERN ALASKA.*

A. F. BUDDINGTON AND J. G. FAIRCHILD.

INTRODUCTION.

The Eocene volcanics of southeastern Alaska are found in local areas within a belt about 200 miles long and 20 miles or less wide, lying in a basin between the Coast Range of the mainland and the Prince of Wales Range of the Alexander Archipelago. They have so far received but casual study in connection with reconnaissance or economic studies,[1] though they and the associated hypabyssal intrusives warrant a thorough systematic investigation. This paper presents a set of chemical analyses and petrographic descriptions of a suite of specimens collected by Buddington, and in large part analyzed by Fairchild, as a contribution towards the problem. The two analyses by T. Kameda were made in the laboratory of Professor Grout at the University of Minnesota, at the expense of the Department of Geology, Princeton University. The volcanics and hypabyssal intrusives are in part of normal calc-alkalic character but in part they belong to types higher than normal in alkalies and characterized by sodic minerals such as riebeckite, analcite, and albite.

Chemical Analyses of Eocene Lavas, Southeastern Alas[illegible]a.

	1	2	3	4	5	6	7	8	[illegible]	10
SiO_2	46.60	48.66	51.45	52.05	53.40	57.70	67.01	72.62	75[illegible]7	76.18
Al_2O_3	14.55	13.40	16.30	15.03	13.35	16.28	13.94	10.17	9[illegible]9	12.95
Fe_2O_3	2.49	1.29	2.43	2.78	2.58	2.88	1.00	4.60	1.2[illegible]	none?
FeO	9.70	11.58	7.20	5.54	11.25	6.00	3.47	1.88	3.3[illegible]	2.05
MgO	9.51	8.72	3.16	4.94	2.33	1.55	0.45	0.10	0.10	[illegible]race?
CaO	8.59	8.92	7.45	9.27	6.58	5.30	1.90	0.10	0.10	0.05
Na_2O	3.61	3.34	2.77	2.33	3.80	4.90	5.63	4.53	2.49	3.33
K_2O	1.28	.80	2.33	1.01	1.36	0.89	2.92	4.78	4.46	4.59
H_2O-	.04	.10	0.50	1.18	.68	.45	0.32	0.08	0.03	0.02
H_2O+	.12	.17	2.52	2.66	1.50	1.35	2.51	0.37	1.21	0.85
TiO_2	2.73	2.77	2.38	1.42	2.03	0.91	0.40	0.35	0.65	0.15
CO_2	....	none	0.66	1.86	.61	1.08	.65	trace	trace	trace
P_2O_5	.54	0.35	0.35	.28	.75	0.56	.08	trace	.05	trace

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	1	2	3	4	5	6	7	8	9	10
SO_3	....	....	....	....	....	.04	.07	....	0.10	....
F	....	none	none	.06	none	none	none	....	....	....
S	....	trace?	0.02	none	.07	....	....	trace?	....	0.03
V_2O_3	....	.03	0.03	.02	trace	none	none	none	none	none
MnO	.19	.12	0.12	.07	.13	0.16	.08	trace	none	none
BaO	....	none	none	.05	.06	0.07	.09	none	none	none
SrO	....	none	none	trace	none	0.02	none	none	none	none
FeS_2	....	none	none	none	....	....	....	none	0.97	none
ZrO_2	....	....	....	.02	trace	....	....	....	....	....
Cr_2O_3	....	....	....	.03	none	none	....	....	....	....
Total	99.95	100.25	99.67	100.60	100.48	100.14	100.52	99.58	99.54	100.20
Deduct O for F and S ..				.03	.04					
				100.57	100.44					

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1. Analyst, T. Kameda.
2, 3, 6, 7, 8, 9, and 10. Analyst, J. G. Fairchild.
4 and 5. Analyst, R. C. Wells.
6, 9, and 10. BeO none by Geo. Steiger.

Norm Composition for Eocene Lavas, Southeastern Alaska.

	1	2	3	4	5	6	7	8	9	10
Quartz	....	....	5.11	11.40	7.68	12.96	18.21	29.43	41.70	37.44
Orthoclase .	7.51	4.73	13.85	6.22	8.44	5.56	17.38	28.35	26.69	27.24
Albite	22.01	28.30	23.58	19.65	31.96	41.40	47.68	25.68	20.96	28.30
Anorthite	19.88	19.04	25.02	27.38	14.18	15.98	4.17	....	.28	.28
Corundum ..	....	....	....	....	....	1.32	....	....	.31	2.35
Nepheline ...	4.54	....	....	....	....	....	....	....	....	....
Acmite	....	....	....	....	....	....	....	11.09	....	....
Diopside	15.76	18.89	7.79	4.26	8.76	....	.60	.50	....	....
Hypersthene.	....	.95	11.44	16.23	16.50	11.42	5.80	2.49	4.21	3.43
Olivine	19.98	20.15	....	....	....	....	....	....	....	....
Magnetite ..	3.60	1.85	3.48	3.94	3.71	4.18	1.39	1.16	1.86	....
Ilmenite	5.08	5.24	4.46	2.62	3.85	1.69	.77	.62	1.23	0.38
Apatite	1.55	0.90	.92	.74	1.87	1.49	.19	....	.15	....
Calcite	....	....	1.15	4.20	1.40	2.45	1.50	....	....	....
Pyrite	....	....	....	....	....	....	....	....	.97	....

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(1) Olivine basalt, north island of Castle Island group, Duncan Canal, Kupreanof Island.
(2) Olivine basalt, east of Mitchell Point, Kupreanof Island.
(3) Basalt, considerably altered, 6½ miles north of Pt. Barrie, Keku Straits, Kupreanof Island.
(4) Labradorite basalt, Sumner Strait, 3 miles east of Pt. Barrie, Kupreanof Island.
(5) Andesite, near center of S.W. side of Conclusion Island, Keku Straits.
(6) Andesite, headland about center of N.E. side of Three Mile Arm, Kuiu Island.
(7) Quartz keratophyre, 1½ miles south of Seclusion Harbor, Kuiu Island.
(8) Riebeckite-albite microgranite (Paisanite), intrusive sill or laccolith. South side of island group at North end of Keku Straits.
(9) Rhyolite porphyry, south side of Kupreanof Island, 7½ miles east of Pt. Barrie.
(10) Rhyolite, Sumner Strait, west side of east island of Level Islands group.

PETROGRAPHIC DESCRIPTIONS.

The olivine basalt (No. 1) is an aphanitic black rock dotted with a few small phenocrysts of yellow olivine. In the field, nodules of olivine up to several inches in diameter are common. In thin section the rock is holocrystalline, composed of a groundmass of very small laths of plagioclase (albitic labradorite, 0.05 mm. or less in width) and monoclinic pyroxene with abundant associated accessory minute grains of magnetite and plates of ilmenite, and with a rude flow of structure. There are numerous phenocrysts of euhedral olivine 0.2-0.4 mm. in diameter, with a very few up to 3 mm., though the mode shows somewhat less olivine than is indicated by the norm. There is no alteration whatever. The phenocrysts of olivine are a magnesium-rich variety ($Fo_{86}Fa_{14}$). In the field this rock shows a well-developed columnar jointing.

Olivine basalt (No. 2) is a dense, medium-gray rock mottled with minute yellowish brown crystals of olivine. In thin section the rock is found to be holocrystalline, except for a very little interstitial palagonite, and to consist of a mat of labradorite laths with grains of monoclinic pyroxene, olivine, and accessory small granules of magnetite and plates of ilmenite. The rock is very fresh. The olivine is of early crystallization in grains about 0.2-0.4 mm. in diameter. It is present in a considerably smaller percentage than is indicated by the norm. The plagioclase is labradorite (Ab_4An_6). In the field this rock exhibits a fissile, platy structure parallel to the surface of the flows.

The basalt (No. 3) is a gray-green aphanitic rock with a few small visible crystals of plagioclase. In thin section it is found to be holocrystalline and to consist of a mat of plagioclase laths in a groundmass of altered ferromagnesian mineral with many minute grains of magnetite and plates of ilmenite. The alteration products consist of chlorite, epidote, and a little carbonate. The plagioclase is also in part altered to epidote and carbonate. The plagioclase varies from andesine-labradorite to more sodic varieties. The green hue of the rock is due to the alteration products.

Labradorite basalt (No. 4) is a dark gray rock with numerous plagioclase phenocrysts 3 to 7 mm. in length in a dense groundmass. Occasionally the plagioclase is a centimeter in length. In thin section the rock shows a mesh of plagioclase laths with intersertal granules or granular aggregates of monoclinic pyroxene, plates of ilmenite, minute granules of magnetite and interstitial colorless cryptocrystalline areas. The pyroxene is much altered to chlorite and carbonate. There are a few minute vesicles with calcite, chlorite, and locally a little quartz. The larger plagioclase crystals are an albitic labradorite. In the field there are local amygdaloidal facies to the basalt flows of this type.

The andesite (No. 5) is a dull black rock without a trace of phenocrysts. In thin section it is seen to be hyalocrystalline with hyalopilitic texture and pronounced fluxion structure. There are microscopic laths of plagioclase, a trifle more albitic than Ab$_5$An$_3$ and numerous grains and rods of monoclinic pyroxene in a glass groundmass. Skeletal magnetite and ilmenite plates also occur in the glass. In the field the rock of this flow shows a very coarse pillow-like structure, in part with radial joints, and in part disintegrated to form a flow breccia.

Andesite (No. 6) is a dark gray aphanitic rock without phenocrysts. In thin section the rock has a pilotaxitic texture with a little interstitial glass in part occurring in small local patchy areas of a yellow-brown color. The plagioclase occurs mostly as microlites, but laths up to 0.5 mm. in length are common, as are microscopic grains of monoclinic pyroxene and magnetite, the latter in part with a skeletal growth. The larger plagioclase laths are a trifle more anorthitic than Ab$_5$An$_5$.

The quartz keratophyre (No. 7) is a black glassy rock with a few small visible laths of plagioclase. It has a conchoidal fracture, and is gray and translucent in thin slivers. In thin section the rock has a hyalocrystalline groundmass and a hyalopilitic texture. It is traversed by a few fractures faced with epidote. There are about 5 per cent by volume of small phenocrysts comprising 3.6 per cent plagioclase in laths 1 to 2 mm. long, 1 per cent monoclinic pyroxene, and 0.34 per cent magnetite, each in small grains. The phenocrysts are all euhedral. The groundmass consists of microlites with a pronounced fluxion structure in a glass matrix. The plagioclase phenocrysts are andesine, a trifle more albitic than Ab$_6$An$_4$, and the microlites must be albite. The pyroxene is in considerable part altered to calcite and to a slight extent to chlorite.

The riebeckite-albite microgranite (No. 8) forms a sill or laccolith in Eocene sandstone and conglomerate. It is a light green-gray to ash-colored rock with vesicles up to a centimeter in diameter, lined with drusy coatings of quartz and riebeckite. It has a fine grain, and in thin section is found to consist of a microgranitic aggregate of riebeckite, quartz, and feldspar. The riebeckite forms about 15 per cent. This rock was originally described as a dacite porphyry on the basis of a study of a chilled facies. The feldspar of the specimens studied is clouded by a slight weathering. No distinct twinning bands could be seen in the feldspar, and the chemical analysis would seem to indicate anorthoclase.

The rhyolite porphyry (No. 9) is a white to pale pinkish gray rock with abundant small phenocrysts of quartz and glassy feldspar (soda-sanidine) in a dense groundmass. In thin section the groundmass is found to consist of micrographic and micrographitic intergrowths of quartz and feldspar with corroded phenocrysts of quartz and euhedral crystals of feldspar. Minute grains of magnetite are scattered throughout the rock. There is a little secondary iron-staining due to weathering. The quartz phenocrysts are about 2 mm. in diameter, and the feldspar phenocrysts are up to 3 mm. in length. The rock is slightly altered to clay minerals.

The rhyolite (No. 10) is a beautifully flow-banded rock with alternating thin white and light green bands and a dense aphanitic texture. In thin section the rock exhibits a cryptocrystalline texture with thin veinings of secondary quartz parallel to the fluxion structure. There is a little sericitic alteration.

COMMENTS ON FIELD RELATIONS OF ROCKS.

The lavas in general have gentle dips, and the field relations of the various types are in general not adequately known.

The rhyolites of analyses 9 and 10 were chosen as representative of the siliceous volcanics near the base of the Eocene section, usually overlying a normally sedimentary series of beds.

The olivine basalts, analyses 1 and 2, are characteristic of the lavas near Pt. Mitchell on Sumner Strait and on the Castle Islands of Duncan Canal. They are thought to be later than the rhyolites.

The basalts, Nos. 3 and 4, probably belong to a series in general younger than the rhyolites. The basalt No. 4 is a very common type for 6 miles east of Pt. Barrie on Sumner Strait. Basalt forms the bulk of many of the mountains in the areas occupied by the Eocene volcanics. They are, however, quite inadequately represented in the set of analyses here presented.

The andesitic types, Nos. 5, 6, and 7, are characteristic of the volcanics forming much of the islands and coast south of Seclusion Harbor on the east side of Kuiu Island, Conclusion Island, and the islands and reefs north of Conclusion Island. These flows often show a rough polygonal jointing, and usually have a platy parting parallel to the fluxion structure and approximately at right angles to the columns.

CHEMICAL INTERRELATIONS.

The olivine basalts (1 and 2), the basalts (3 and 4), and the rhyolites (9 and 10) are normal types. The rhyolites are, however, noteworthy for very low lime and magnesia.

The andesitie lavas (5, 6, and 7) show a marked tendency towards the development of a higher soda and alkali content than normal. This series would lie on the border line between the alkali-calcic and calc-alkalic sequences as defined by Peacock,[2] with the combined alkalis equaling lime at about 57 per cent SiO_2.

HYPABYSSAL INTRUSIVES.

Associated with the belt of volcanics there are also local masses of hypabyssal intrusives.[3] In part these consist of olivine and pyroxene diabase or gabbro and granite or granite porphyry of normal character. In part there are analcite gabbros with interstitial analcite up to ten per cent of the rock of apparently primary origin, and riebeckite-albite micrograinte with about 15 per cent riebeckite. It is thus evident that certain of the intrusives, like certain of the lavas, have a tendency to develop high soda facies.

CRETACEOUS(?) AUGITE BASALT PORPHYRY.

On the west side of Etolin Island, opposite Marsh Island, dikes of augite basalt porphyry are very common in sediments of Lower Cretaceous age. They resemble in many ways the greenstone volcanics of Jurassic or Lower Cretaceous age which are a major formation in southeastern Alaska, but are so much fresher and unaltered as to suggest a Tertiary age. They are quite different from the known Tertiary lavas, however, and are thought to be of lower Cretaceous age and genetically connected with overlying lavas.

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[2] Peacock, M. A., Classification of igneous rock series; Jour. Geol., **39**, 54-67, 1931.

[3] Buddington and Chapin, Geology and Mineral Deposits of Southeastern Alaska; U. S. Geol. Survey Bull. **800**, pp. 222-223, 273-275, 1929.

A chemical analysis and the normative composition of a typical specimen from the center islet of Steamer Rocks off the west coast of Etolin Island is given below:

SiO_2	48.17
Al_2O_3	12.64
Fe_2O_3	5.87
FeO	6.46
MgO	8.73
CaO	11.76
Na_2O	1.99
K_2O	.63
H_2O+	2.53
H_2O-	.19
TiO_2	.75
P_2O_5	.22
MnO	.20
	100.14

Norm Composition	
Quartz	0.81
Orthoclase	3.89
Albite	16.77
Anorthite	23.63
Diopside	26.73
Hypersthene	15.25
Apatite	.56
Magnetite	8.58
Ilmenite	1.39

The rock has a medium-gray dense groundmass with abundant phenocrysts of green diopsidic augite 3 to 5 mm. in diameter, and plagioclase crystals 2 to 3 mm. in length. In thin section the plagioclase phenocrysts are found to be a calcic labradorite and the groundmass to consist of very small labradorite laths, granules of monoclinic pyroxene, and minute grains of magnetite. There is a little chloritic alteration.

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CALCAREOUS "PIPES" IN THE QUATERNARY OF ECUADOR.

GEORGE SHEPPARD.

The tablazo (Quaternary) formations of southern Ecuador in the coastal region to the west of the Cerros de Chanduy, are characterized by the presence of unusual branching and tubular structures, or "pipes," occurring in certain horizons in considerable profusion. The structures are calcareous in composition and appear to have been formed by the downward penetration of roots from an ancient Quarternary land surface and, in addition, they had the faculty of abstracting almost pure carbonate of lime from the matrix of the country rock. The rootlets themselves have also formed channels through which atmospheric waters percolated from above, and hence assisted in the aggregation of the chalky nodules which are now found in the vicinity of the cavities. The "pipes" of lime carbonate are white in color and are surrounded by a growth of secondary nodules which are rounded after the form of true beach pebbles (Fig. 1). This rounded appearance, however, has nothing to do with erosion, as it is simply the shape of the nodular mass induced through the medium of the

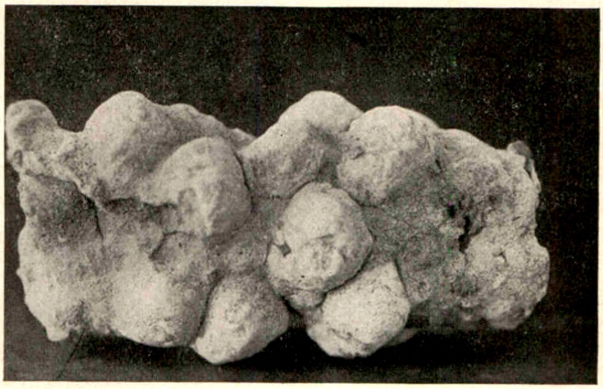

Fig. 1. Calcareous "pipe" with subsidiary nodules.

subsidiary rootlets. The lime carbonate is a very pure form as it rapidly dissolved in hydrochloric acid, leaving only a few sand grains as a residue. In several cases these irregular tubes follow the bedding planes of the looser tablazo material (Fig. 2). The rootlet origin of the branched structures is beyond doubt as the actual woody tissue of the root is occasionally found as a core to the "pipe."

A section of the Quarternary (Fig. 3) in which the calcareous structures occur is found on the sea coast at the settlement of Real., the different stages of the deposit being described as follows: (a) Surface sand and fine soil. This consists of a "loess" or similar loosely aggregated deposit, the great part being blown sand. The sand itself passes upwards into the surface soil which exhibits "badland" features, and contains marine shell fragments and numerous well-preserved land shells (*Bulimus* sp.). The lower part (b) of this section is coarser in texture and develops into a pebble beach deposit or conglomerate, which contains rolled quartzites and dolerites, etc. The beach deposit varies from 1½ to 2 feet in thickness. Deposit (c) includes 2 feet of coarse material consisting

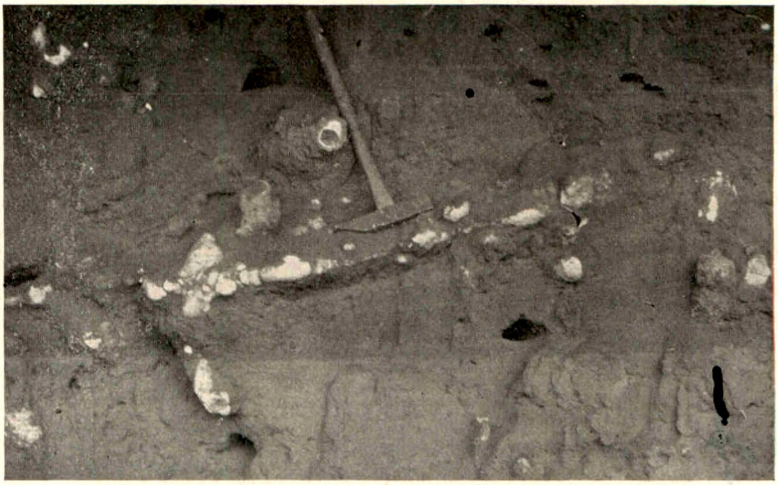

Fig. 2. "Pipes" occurring in lower part of deposit (d) caused by rootlets following the bedd.ng plane.

largely of marine shells such as *Turritella, Conus, Ostrea, Pecten,* etc. Then follows (d) a considerable development of fine to coarse glauconitic sand, devoid of fossils, in which the root-tubes and branched forms described above are found

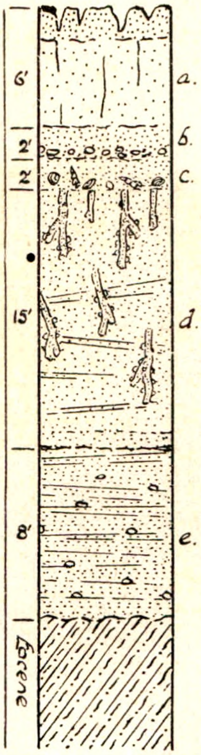

Fig. 3. Coast section in Quaternary and Tertiary near Real., South-western Ecuador; (a) Loess, or fine sand passing upwards into surface soil, with shell fragments (marine) and *Bulimus* sp.; (b) Coarse sand, beach pebbles at base; (c) Shell bed, casts of *Turritella, Conus,* etc.; (d) Glauconitic sand with calcareous "pipes," no fossils, occasionally current-bedded; (e) Current-bedded sand with nodules. Eocene shales.

(Figs. 3, 4), this being succeeded by 8 feet (e) of loose, current-bedded sand with calcareous nodules, the latter being genetically associated with the "pipes." The whole sequence is Quarternary in age and rests unconformably upon the Eocene.

The sand in which the tubular structures are found consists principally of colorless and ferruginous quartz grains, glauconite, large flakes of mica, and black quartzite. The material

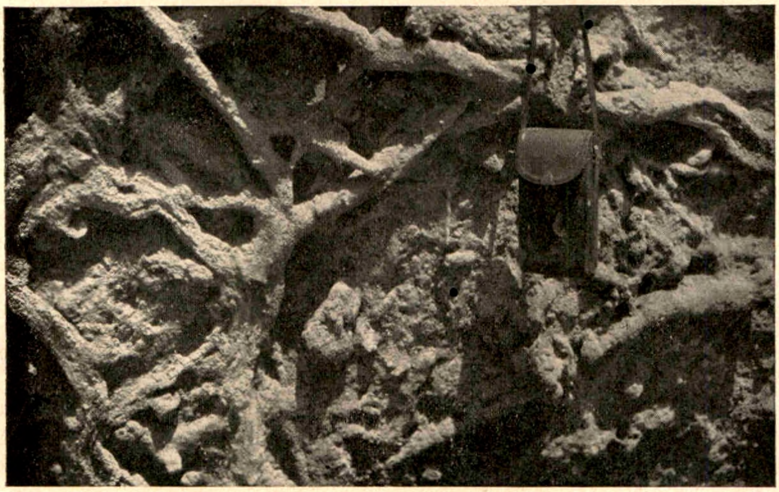

Fig. 4. General aspect of calcareous "pipes," found in the upper part of deposit (d).

inside the larger tubes appears to be the same as above, only of larger grains and with a considerable amount of calcareous silt.

GUAYAQUIL, ECUADOR.

THE SYSTEM $CaO-Na_2O-Al_2O_3$.*

ABSTRACT.

L. T. BROWNMILLER and R. H. BOGUE

A part of the system $CaO-Na_2O-Al_2O_3$, in the region low in Na_2O, has been investigated by the methods of Phase Equilibria. The stability fields, boundary curves and invariant points have been defined. Optical and X-ray data are presented and ternary diagrams introduced to indicate the composition and temperature relations and the course of crystallization in the system.

INTRODUCTION.

The studies reported in this paper are in continuation of a series begun several years ago to determine the constitution of portland cement clinker and the part played by each of the compounds in the manufacture and utilization of that product. To-day those studies are fairly complete for the principal constitutents of portland cement, namely for CaO, SiO_2, Al_2O_3, Fe_2O_3 and MgO; and from them the modern ideas on the constitution of cement have been evolved.[1]

Besides these components, there are many others occurring in small amounts in cements. Of the minor components, soda is one of the more important since it is common to practically all cements. Therefore a continuation of those studies has been made to determine the combinations which soda is capable of forming with the other constitutents of the cement.

The system $CaO-Na_2O-Al_2O_3$ has now been examined and constitutes the subject of this report. This system, however. was not explored completely. Not only would special methods have to be adopted to solve it entirely but, in cements, the concentration of soda is small; hence, the studies in the system could be confined to compositions low in Na_2O. Apparently only one compound of CaO and Al_2O_3, $3CaO.Al_2O_3$, occurs in normal portland cements; accordingly that region of the diagram $CaO-Na_2O-Al_2O_3$ in which $3CaO.Al_2O_3$ occurs is the field of greatest importance. Nevertheless, because of the complexity of the system, other portions of the diagram had to be investigated to understand fully the relations in that region.

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* Publication approved by the Director of the National Bureau of Standards, U. S. Department of Commerce. Paper No. 25 of the Portland Cement Association Fellowship at the Bureau of Standards.

[1] See Bibliography at the end of paper for reference.

EXPERIMENTAL METHOD.

Because of the volatility of Na_2O at temperatures above 900°,* somewhat special methods had to be used in preparing the samples. Base compositions of CaO and Al_2O_3 were weighed in various proportions, thoroughly mixed by stirring in a small amount of water and then burned in a platinum resistance furnace. A portion of about 5 g of this base composition was weighed and to it the third component, Na_2O, was added in the form of Na_2CO_3. The compositions of the raw materials are indicated in Table I. An excess of the sodium carbonate over that desired in the final sample was required since some Na_2O is volatilized on heating. After dry mixing of the components of the ternary composition, it was burned at a temperature of about 1400°, pulverized and reburned at a higher temperature. Burning was done in an open platinum boat in a platinum resistance furnace. After cooling in a dessicator, the sample was weighed and from the difference in weight the amount of Na_2O remaining in the mixture was calculated.

Table I.

Partial analysis by Carlson				Partial analysis by J. T. Baker Chemical Co.	
Calcium Carbonate Per Cent		Alumina Per Cent		Sodium carbonate Per Cent	
CaO	56.04	Al_2O_3	98.48	Insoluble	.02
MgO	.07	SiO_2	.01	Cl	.005
R_2O	.06	Fe_2O_3	.002	SO_4	.004
R_2O_3	.05	CaO	nil	R_2O_3	.005
SiO_2	.01	Cl	trace	SiO_2	.005
Loss	43.71	SO_3	trace		
		Loss	1.42		

Relatively low temperatures were used for the first burning because this procedure resulted in less loss of Na_2O by volatilization than obtained with high initial burning temperatures.

The amount of Na_2O lost on subsequent heatings at 1400°–1500° was found to vary from less than one per cent of the total weight in samples low in soda to somewhat larger percentages in samples high in soda. In making up the compositions for these studies, an excess of about 25 per cent of sodium carbonate above the theoretical amount required was weighed into the base compositions, but this percentage excess could be reduced somewhat if the first burning were made at a temperature as low as about 1100°. On twice burning such a mixture at 1400°–1500° the composition was found usually to be within one per cent of that desired. Further adjustments could then be made to give the precise compositions required.

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* Temperatures are given in degrees C.

The second heating of the samples was necessary before final weighing because frequently not all of the carbon dioxide was evolved during the first burning, as evidenced by effervescence on treating with hydrochloric acid. Before final weighing, all samples were heated at least once to temperatures of about 1500°.

Table II gives a few data on the amount of Na_2O volatilized from these samples heated in an open platinum container. The loss usually was less than one per cent after the Na_2O was once combined; but the amount of the loss was found to depend somewhat on the composition, the temperature and the time of heating.

TABLE II. Data showing the per cent loss in Na_2O following several heat treatments.

	Sample H U			Sample H T			Sample H S		
	Temp.	Na_2O	Loss	Temp.	Na_2O	Loss	Temp.	Na_2O	Loss
Na_2O added (per cent)	....	9.0	..	....	20.0	..	....	17.0	..
Na_2O after 1st heating	1450	6.3	2.7	1450	13.8	6.2	1450	12.5	4.5
Na_2O after 2d heating	1425	5.9	.4	1400	13.3	.5	1425	11.8	.7
Na_2O after 3d heating	1525	5.0	.9	1475	12.6	.7	1425	11.5	.3

These samples were then finely ground and portions taken for determining the temperature relations in the system. Heating curves were not obtained because the thermoelements are attacked by the Na_2O. Hence the quenching method was used exclusively. In this method a small charge is enclosed in pure platinum foil and suspended in a quenching furnace[2] capable of reaching 1630°. The samples were usually held in the furnace at desired temperature for 20 minutes, which was sufficient time for the attainment of equilibrium in most cases. Samples were then quenched in mercury or water and examined under a petrographic microscope. Samples dropped in mercury float on the surface and in some regions of the diagram cooling is not rapid enough to prevent quench growths; hence water was frequently used. Crystallizations during quenching were troublesome in the regions in which the ternary compound $8CaO.Na_2O.3Al_2O_3$ crystallized. They can usually be recognized by wavy extinction under crossed nicols and by a brown color in ordinary light; also the refractive indices of such growths are slightly higher than those of the glass but never as high as those of the true crystals. Often these growths form concentric bands around the primary phase.

The samples finally obtained as described above were too small for analysis but the examination of other samples treated

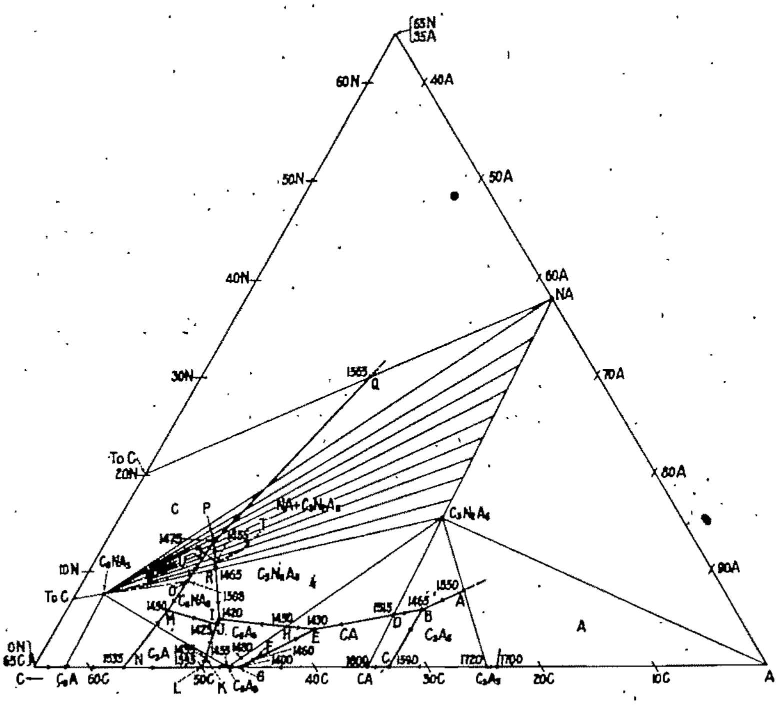

Fig. 1—Diagram Showing Fields of Primary Crystallization and the Binary Systems Within the Ternary System CaO-Na_2O-Al_2O_3
C-CaO; A-Al_2O_3; N-Na_2O.

at corresponding temperatures indicated that the amount of soda lost due to volatilization from these especially prepared specimens was considerably less than that shown in Table II. The samples listed in Table II were burned in open platinum boats whereas the samples for quenching were always carefully enclosed in platinum foil. Furthermore, in working with samples just above (by ½ per cent of Na_2O) the boundary between the fields of $3CaO.2Na_2O.5Al_2O_3$ and $5CaO.3Al_2O_3$, the primary phase always was $3CaO.2Na_2O.5Al_2O_3$ whereas, if the amount of Na_2O lost were appreciable, the composition, after heating different samples of the same original composition for varying periods, would have been shifted to throw it into the field of $5CaO.3Al_2O_3$. It is felt that if such were the case different quenches of the same composition should have shown different primary phases. Such irregularities did not occur.

Because of the reaction of soda with the thermoelements, frequent calibration was necessary. It is believed that the reaction is principally with the rhodium and not with the platinum. Fused samples containing Na_2O were frequently colored pink or brown and in such cases the samples showed reaction with the metal. No such discoloration was noticed in samples wrapped in the pure platinum foil and the foil could usually be pulled from melted samples leaving a charge with a smooth surface and no indication of reaction.

The optical properties were determined with a petrographic microscope and the powder X-ray diffraction apparatus was employed to obtain the interplanar spacings of the compounds and for the identification of the phases in the samples. The radius of the cassettes is 8″ and the effective wave length of the rays is 0.712 A. U.

The principal results of the study are shown diagrammatically in Fig. 1.

THE BINARY SYSTEMS OF THE COMPONENTS.

The System CaO-Na_2O.—No evidence was obtained of the existence of any binary compound in this system. When samples made of these components were heated, the Na_2O was nearly completely volatilized and the optical properties of the CaO were apparently unchanged.

The System CaO-Al_2O_3.—This system was studied by Rankin and Wright. The relations are given in their report: "The Ternary System CaO-Al_2O_3-SiO_2."[8]

Four compounds were found: $3CaO.Al_2O_3$ which dissociates at 1535° ± 5° into CaO and liquid; $5CaO.3Al_2O_3$ which melts at 1455° ± 5°; $CaO.Al_2O_3$ which melts at 1600° ± 5°; and $3CaO.5Al_2O_3$ which melts at 1720° ± 10°. The $3CaO$.-

Al_2O_3 does not form a eutectic with CaO but the composition CaO 57, Al_2O_3 43 is the quadruple point at which the two compounds are stable in contact with liquid and vapor, the equilibrium temperature being 1535° ± 2°. $3CaO.Al_2O_3$ forms a eutectic with $5CaO.3Al_2O_3$ having the composition CaO 50, Al_2O_3 50 which melts at 1395° ± 5°. $5CaO.3Al_2O_3$ forms a eutectic with $CaO.Al_2O_3$ having the composition CaO 47, Al_2O_3 53 which melts at 1400° ± 5°. $CaO.Al_2O_3$ forms a eutectic with $3CaO.5Al_2O_3$ of the composition CaO 33.5, Al_2O_3 66.5 which melts at 1590° ± 5°. $3CaO.5Al_2O_3$ forms a eutectic with Al_2O_3 of the composition CaO 24, Al_2O_3 76 which melts at 1700° ± 10°. It should be noted that the composition range within which $3CaO.Al_2O_3$ occurs as a primary phase on the liquidus curve is incorrectly stated on page 10 of the above paper, to be from CaO 50, Al_2O_3 50, to CaO 59, Al_2O_3 41. The range is given correctly in Tables B and C on pages 77 and 78 of the same paper to be from CaO 50, Al_2O_3 50 to CaO 57, Al_2O_3 43.

The interplanar spacings of the X-ray diffraction pattern of $CaO.Al_2O_3$ and $3CaO.5Al_2O_3$ are given in Tables III and IV respectively. Those of CaO, $3CaO.Al_2O_3$ and $5CaO.3Al_2O_3$ have been reported previously from this laboratory[4] but, as

TABLE III. Interplanar Spacings of $CaO.Al_2O_3$.

Line No.	d_{hkl}	Intensity*	Line No.	d_{hkl}	Intensity*
1	3.70	m	19	1.681	w
2	3.40	w	20	1.656	m
3	3.31	w	21	1.605	ww
4	3.18	m	22	1.578	m
5	2.96	ss	23	1.523	sb
6	2.85	m	24	1.481	w
7	2.68	w	25	1.461	m
8	2.52	s	26	1.450	m
9	2.41	s	27	1.410	m
10	2.335	w	28	1.363	wwb
11	2.195	m	29	1.341	wwb
12	2.140	m	30	1.295	wwb
13	2.080	w	31	1.278	ww
14	2.025	m	32	1.255	ww
15	1.963	w	33	1.181	m
16	1.925	s	34	1.153	m
17	1.835	w	35	1.069	ww
18	1.750	ww			

* ss = very strong; s = strong; m = medium; w = weak; ww = very weak; b = broad.

TABLE IV. Interplanar Spacings of $3CaO.5Al_2O_3$.

Line No.	d_{hkl}	Intensity	Line No.	d_{hkl}	Intensity
1	3.62	m	22	1.800	m
2	3.50	ss	23	1.759	m
3	3.09	s	24	1.679	w
4	2.97	s	25	1.624	m
5	2.87	s	26	1.553	m
6	2.75	s	27	1.533	sb
7	2.72	s	28	1.479	ww
8	2.59	ss	29	1.451	wb
9	2.52	s	30	1.368	m
10	2.43	mb	31	1.332	w
11	2.32	m	32	1.306	w
12	2.27	m	33	1.284	w
13	2.185	m	34	1.252	w
14	2.125	ww	35	1.178	w
15	2.055	mb	36	1.153	ww
16	1.998	w	37	1.134	w
17	1.960	m	38	1.025	ww
18	1.923	ww	39	.962	ww
19	1.900	m	40	.897	ww
20	1.866	ww	41	.893	ww
21	1.836	ww	42	.875	ww

more satisfactory patterns of the latter two compounds have recently been obtained, these are given also in Tables V and VI.

TABLE V. Interplanar Spacings of $3CaO.Al_2O_3$.

Line No.	d_{hkl}	Intensity	Line No.	d_{hkl}	Intensity
1	4.07	m	28	1.486	w
2	3.32	w	29	1.449	w
3	3.03	w	30	1.426	ww
4	2.83	w	31	1.404	w
5	2.77	w	32	1.360	w
6	2.69	ss	33	1.345	s
7	2.57	ww	34	1.315	ww
8	2.46	ww	35	1.262	ww
9	2.400	w	36	1.231	w
10	2.375	w	37	1.204	s
11	2.270	w	38	1.165	w
12	2.200	m	39	1.155	ww
13	2.135	ww	40	1.099	w
14	2.085	w	41	1.053	ww
15	2.033	w	42	1.034	ww
16	1.981	w	43	1.017	s
17	1.947	w	44	.998	ww
18	1.905	s	45	.966	ww
19	1.821	w	46	.897	m
20	1.785	ww	47	.850	ww
21	1.731	m	48	.811	ww
22	1.693	ww	49	.777	ww
23	1.669	ww	50	.746	ww
24	1.640	w	51	.726	ww
25	1.611	w	52	.694	ww
26	1.554	ss	53	.652	ww
27	1.512	ww	54	.620	ww

TABLE VI. Interplanar Spacings of $5CaO.3Al_2O_3$.

Line No.	d_{hkl}	Intensity	Line No.	d_{hkl}	Intensity
1	3.77	m	27	1.305	m
2	3.18	m	28	1.290	ww
3	2.98	s	29	1.274	w
4	2.67	ss	30	1.260	w
5	2.55	m	31	1.234	w
6	2.44	s	32	1.207	w
7	2.34	m	33	1.187	ww
8	2.180	s	34	1.171	w
9	2.055	w	35	1.140	ww
10	1.943	s	36	1.110	m
11	1.906	w	37	1.091	w
12	1.846	w	38	1.084	w
13	1.800	ww	39	1.066	w
14	1.764	w	40	1.057	w
15	1.728	m	41	1.048	ww
16	1.694	w	42	1.031	w
17	1.660	s	43	1.017	w
18	1.629	m	44	.989	ww
19	1.599	s	45	.968	ww
20	1.554	w	46	.927	w
21	1.520	m	47	.916	ww
22	1.493	w	48	.900	ww
23	1.472	m	49	.890	w
24	1.390	s	50	.857	ww
25	1.353	ww	51	.848	ww
26	1.336	w			

The System Na_2O-Al_2O_3.—Matignon[5] found that there exists in the system Na_2O-Al_2O_3 one compound, $Na_2O.Al_2O_3$, which has a melting point at 1650°. No optical properties were given.

The system Na_2O-Al_2O_3 was only partially investigated by the present authors due to the difficulties of working with compositions high in Na_2O and to the high melting temperatures in the region approaching Al_2O_3.

On heating a mixture of the composition $Na_2O + Al_2O_3$ (37.8 per cent Na_2O; 62.2 per cent Al_2O_3) to 1650°, a homogeneous phase was obtained; there was no melting or dissociation at that temperature. The melting point could not be determined because of the temperature limitations of the furnace.

The compound $Na_2O.Al_2O_3$ was found to crystallize as colorless rounded grains. It is biaxial negative with indices of refraction; $\alpha = 1.566 \pm .003$, $\beta = 1.575 \pm .003$, $\gamma = 1.580 \pm .003$. The optic axial angle is medium small, about 30°.

Twinning commonly occurs. The interplanar spacings of the X-ray diffraction pattern are given in Table VII.

No other binary compounds were detected in the system but, on heating a sample containing 3.5 per cent Na_2O and 96.5 per cent Al_2O_3 for short periods at 1100°, corundum and βAl_2O_3 were identified. On heating such samples at 1500°, βAl_2O_3 and $Na_2O.Al_2O_3$ crystallized while corundum was absent. βAl_2O_3 was found to be the stable modification in the system $Na_2O.Al_2O_3$-Al_2O_3 at high temperatures in samples containing as large an amount as 96.5 per cent of Al_2O_3.

TABLE VII. Interplanar Spacings of $Na_2O.Al_2O_3$.

Line No.	d_{hkl}	Intensity	Line No.	d_{hkl}	Intensity
1	2.94	s	19	1.362	s
2	2.68	s	20	1.302	w
3	2.60	ss	21	1.283	w
4	2.55	ss	22	1.176	ww
5	2.38	w	23	1.119	m
6	2.22	ww	24	1.065	ww
7	2.145	w	25	1.048	m
8	1.983	ww	26	1.028	ww
9	1.950	m	27	1.010	w
10	1.869	m	28	.980	ww
11	1.805	w	29	.975	ww
12	1.762	m	30	.955	w
13	1.599	s	31	.918	ww
14	1.523	w	32	.910	ww
15	1.497	s	33	.880	ww
16	1.471	w	34	.805	ww
17	1.458	s	35	.782	ww
18	1.415	m	36	.762	ww

βAl_2O_3 was found to be uniaxial negative and to crystallize as plates with the optic axis parallel to the c-crystallographic axis. It belongs to the hexagonal crystal system. Determination of the indices of refraction on a sample of the compound furnished by the Norton Company gave values: $\omega = 1.678 \pm .003$; $\epsilon = 1.635 \pm .003$. This sample which was made by fusion of Al_2O_3 with Na_2O_3 appeared under the microscope to be practically pure βAl_2O_3. The crystals were large and well developed whereas in the sample referred to above containing 3.5 per cent Na_2O, the small size of the crystals of the βAl_2O_3 prevented satisfactory measurement of the indices of refraction. However, the X-ray diffraction pattern of this sample of βAl_2O_3 and that of the sample furnished by the Norton Company[6] were identical.

THE TERNARY COMPOUNDS.

Two ternary compounds were found in the system CaO-Na_2O-Al_2O_3: one of a molecular composition $3CaO.2Na_2O.5Al_2O_3$ and the other $8CaO.Na_2O.3Al_2O_3$.

By weight percentages the compound $3CaO.2Na_2O.5Al_2O_3$ contains 20.9 per cent CaO; 15.5 per cent Na_2O; 63.6 per cent Al_2O_3. This compound does not dissociate or melt at any temperature up to 1630°. Optically it is biaxial positive; the mean refractive index is 1.592 ± .005; the birefraction is very weak, about .005; and it crystallizes as rounded grains. The interplanar spacings of the X-ray diffraction pattern of this compound are given in Table VIII.

The compound $8CaO.Na_2O.3Al_2O_3$, having a composition of 54.9 per cent CaO, 7.6 per cent Na_2O and 37.5 per cent Al_2O_3, dissociates into lime and liquid at 1508°. Its composition lies outside the field in which it occurs as a primary phase.

TABLE VIII. Interplanar Spacings of $3CaO.2Na_2O.5Al_2O_3$.

Line No.	d_{hkl}	Intensity	Line No.	d_{hkl}	Intensity
1	4.20	s	32	1.302	w
2	3.91	s	33	1.288	m
3	3.41	m	34	1.263	ww
4	2.97	w	35	1.240	ww
5	2.84	s	36	1.214	ww
6	2.67	w	37	1.188	ww
7	2.58	ss	38	1.161	m
8	2.49	ww	39	1.144	m
9	2.43	w	40	1.162	w
10	2.34	w	41	1.102	w
11	2.25	m	42	1.080	wwb
12	2.20	m	43	1.058	w
13	2.14	m	44	1.051	m
14	2.06	m	45	1.025	ww
15	1.990	m	46	1.014	ww
16	1.934	m	47	1.000	ww
17	1.863	m	48	.975	w
18	1.842	m	49	.951	ww
19	1.805	s	50	.926	ww
20	1.738	m	51	.906	ww
21	1.697	w	52	.854	w
22	1.660	w	53	.841	ww
23	1.600	w	54	.837	ww
24	1.575	w	55	.815	ww
25	1.544	m	56	.812	ww
26	1.499	s	57	.787	ww
27	1.485	s	58	.782	ww
28	1.425	m	59	.744	ww
29	1.391	m	60	.739	ww
30	1.363	m	61	.734	ww
31	1.333	ww	62	.728	ww

It is biaxial negative with a medium optic angle; indices of refraction are $\alpha = 1.702 \pm .003$, $\gamma = 1.710 \pm .003$. When the compound crystallizes as a primary phase, well-formed crystals are readily obtained. They often appear as polyhedrons with hexagonal or octagonal outline. When crystallization of the melt is rapid the compound separates as extremely fine crystalline material. In slowly cooled samples twinning is characteristic.

The compound $8CaO.Na_2O.3Al_2O_3$ was never obtained as a perfectly homogenous phase. Fairly well-crystallized samples were obtained by heating preparations for about two hours just below the dissociation temperature. Longer heating periods were avoided because of possible loss of soda due to volatilization. Neither could the compound be obtained by annealing a glass of its own composition for such a glass could not be prepared since all of the CaO did not go into solution at the temperatures obtainable.

The interplanar spacings of the X-ray diffraction pattern of this compound are given in Table IX.

A consideration of the composition and structure of $8CaO.Na_2O.3Al_2O_3$ is of some interest.

Before the structure of the $8CaO.Na_2O.3Al_2O_3$ had been determined, it was noted that the X-ray diffraction pattern of the new compound was closely similar to that of $3CaO.Al_2O_3$. This suggested that the composition of the compound might lie on the line joining $3CaO.Al_2O_3$ and Na_2O and hence be represented by $3CaO.Al_2O_3$ plus some multiple of Na_2O, just as the ternary compound $3CaO.2Na_2O.5Al_2O_3$ may be represented

TABLE IX. Interplanar Spacings of $8CaO.Na_2O.3Al_2O_3$.

Line No.	d_{hkl}	Intensity	Line No.	d_{hkl}	Intensity
1	3.37	w	15	1.746	w
2	3.03	w	16	1.692	wb
3	2.68	ss	17	1.628	w
4	2.60	w	18	1.558	ss
5	2.53	w	19	1.492	w
6	2.41	w	20	1.347	m
7	2.37	w	21	1.235	w
8	2.20	s	22	1.210	m
9	2.10	w	23	1.103	w
10	2.03	w	24	1.101	w
11	1.915	s	25	1.055	w
12	1.888	s	26	1.019	m very broad
13	1.840	ww	27	.899	w
14	1.797	ww			

by a composition $3CaO.5Al_2O_3$ plus $2Na_2O$. Accordingly, a mixture of $3CaO.Al_2O_3$ and Na_2O was prepared and heated at 1400°; a temperature well below the dissociation temperature of the ternary compound. Following this heat treatment the sample was examined and found to contain considerable free CaO. If the compound were merely an addition product of Na_2O and $3CaO.Al_2O_3$ or a solution of Na_2O in $3CaO.Al_2O_3$, no lime should have been displaced at that temperature. The displacement of CaO in the mixture indicated that the new compound was not such an addition product.

If we consider the composition $8CaO.Na_2O.3Al_2O_3$, we observe that it may be represented as $3(3CaO.Al_2O_3)$ in which one CaO has been replaced by Na_2O. Bragg[7] has shown that in the silicates and associated compounds, the X-ray configuration is dependent upon the framework of the oxygen atoms. That is, when packed as closely as possible, the oxygen atoms form the basis of the structure of the compound whereas the other atoms lie between them. One criterion for such close packing is that the index of refraction of a compound with that structure lies above 1.70; $3CaO.Al_2O_3$ and $8CaO.Na_2O.3Al_2O_3$ both have indices above 1.70. The other atoms merely expand this oxygen lattice.

From the similarity of the X-ray diffraction patterns it would seem that the above conditions fit the case here. It might further be remarked that the crystal structure is a function of the unit cell and not of the chemical molecule. That is, the unit cell is some integral multiple of the chemical molecule and hence there is no difficulty encountered in the consideration of the replacement of one Na_2O for one CaO from three molecules of $3CaO.Al_2O_3$. Thus the unit cell of $3CaO.Al_2O_3$ may contain three times as many molecules as the unit cell of $8CaO.Na_2O.3Al_2O_3$. A solution of the structure of both of these compounds to the end of allocating the exact positions of all of the atoms should be of interest.

In its field of primary crystallization, $3CaO.Al_2O_3$ often crystallizes as well-formed polyhedrons with hexagonal or octagonal outline. In ordinary light these crystals appear similar to the well-formed crystals of $8CaO.Na_2O.3Al_2O_3$. Yet $3CaO.Al_2O_3$ is reported as belonging to the isometric system whereas $8CaO.Na_2O.3Al_2O_3$ does not belong to that system since it is clearly birefracting.

Rankin and Wright[3] have reported that $3CaO.Al_2O_3$ is faintly birefracting, which birefraction they attribute to strain.

In this study, the compounds $3CaO.Al_2O_3$ showed a distinct but weak birefraction when large grains were available; this was noticeable both in the binary system CaO-Al_2O_3 and in the ternary system CaO-Na_2O-Al_2O_3.

Furthermore, Harrington[4] found that his X-ray diffraction patterns of $3CaO.Al_2O_3$ did not altogether conform to the cubic structure and he assigned the compound to a pseudo-cubic system. His samples of $3CaO.Al_2O_3$ were carefully prepared and annealed for long periods in order to avoid strain in the crystals. Such treatment, however, did not alter the X-ray diffraction patterns. Hence, from these structural considerations, it is suggested that $3CaO.Al_2O_3$ does not belong to the isometric system and only because of its extremely low birefraction has it been so classified.

The nature of the compound $3CaO.2Na_2O.5Al_2O_3$ will be discussed more fully below.

THE STABILITY FIELDS.

The fields of stability of the various compounds in the ternary diagram are shown in Fig. 1. Each of the components as well as all of the binary and ternary compounds which were found have stability fields in the system.

In the field of $3CaO.5Al_2O_3$, both the stable and unstable forms of that compound were formed. Usually the stable modification crystallized from the melt although occasionally the unstable modification appeared. No definite region of stability was found for either form.

The compounds $5CaO.3Al_2O_3$ does not crystallize as such in the presence of Na_2O but as a solid solution of soda, in some form, in $5CaO.3Al_2O_3$. Whenever reference is made in this paper to the compound $5CaO.3Al_2O_3$ in the ternary diagram, this solid solution is indicated. As the amount of solid solution increases to its maximum, containing about 1 per cent of Na_2O, the index of refraction of $5CaO.3Al_2O_3$ is lowered from 1.61 to 1.59. The X-ray diffraction pattern shows a regular shift of the position of its lines as the amount of soda taken up is increased.

Whenever $3CaO.Al_2O_3$ and $8CaO.Na_2O.3Al_2O_3$ crystallized from the melt, well-formed crystals of both of these compounds were found. The crystals showed considerable similarity in appearance but there was no indication of any solid solution of the two at the liquidus and the boundary curve separating the two fields was easily located.

A boundary separating the fields in which $Na_2O.Al_2O_3$ and $3CaO.2Na_2O.5Al_2O_3$ appear as primary phases could not be located. The properties of the primary phase in the region bounded by the radial lines (Fig. 1), but lying to the right of the boundary RPQ, varied from those of $3CaO.2Na_2O.5Al_2O_3$ through insensible gradations to those of $Na_2O.Al_2O_3$. Throughout this region, also, the product of final crystallization consisted of two phases: $8CaO.Na_2O.3Al_2O_3$ and a second phase which had properties intermediate between $3CaO.2Na_2O.5Al_2O_3$ and $Na_2O.Al_2O_3$. For these reasons it appears probable that a continuous series of solid solutions exists between those two compounds. The consideration may be simplified by regarding $Na_2O.Al_2O_3$ as taking up $CaO.Al_2O_3$ in solution to a limiting composition of $3(CaO.Al_2O_3)+2(Na_2O.Al_2O_3)$. Since this limit cannot be exceeded, it functions as a compound and may properly be regarded as such. The tie-line $8CaO.Na_2O.3Al_2O_3 — 3CaO.2Na_2O.5Al_2O_3$ may thus be considered as expanded to include all compositions up to the position $8CaO.Na_2O.3Al_2O_3 — Na_2O.Al_2O_3$. From the phase-rule viewpoint, that whole area may be regarded as consisting of an infinite number of tie-lines passing from the origin, $8CaO.Na_2O.3Al_2O_3$, to the solid solution line $3CaO.2Na_2O.5Al_2O_3 — Na_2O.Al_2O_3$. It should be pointed out that these tie-lines indicate the mean products of final crystalization but cannot be regarded as crystallization curves. That is, the precise composition of the crystals formed at any given temperature from any given composition of liquid, in this area, can be established only by experimentation[8] which has not been conducted in the present study.

No attempt was made to define a boundary separating the field in which the $Na_2O.Al_2O_3$ appears in solid solution with $3CaO.2Na_2O.5Al_2O_3$ and the field in which $Na_2O.Al_2O_3$ separates as primary phase.

THE QUINTUPLE POINTS.

Three quintuple invariant points were found in the system which represent ternary eutectics, that is, invariant compositions at which three solid phases coexist with liquid and vapor, occurring inside the triangle formed by the three solid phases.[9]

The eutectic for $3CaO.5Al_2O_3$, $CaO.Al_2O_3$ and $3CaO.2Na_2O.5Al_2O_3$ (point B, Fig. 1) occurs at a composition 27.5

per cent CaO, 6.0 per cent Na_2O, 66.5 per cent Al_2O_3 and melts at 1465°.

The eutectic for $5CaO.3Al_2O_3$, $CaO.Al_2O_3$, and $3CaO.2Na_2O.5Al_2O_3$ (point E) occurs at a composition 38.0 per cent CaO, 4.0 per cent Na_2O, 58.0 per cent Al_2O_3 and melts at 1430°.

The eutectic for $5CaO.3Al_2O_3$, $8CaO.Na_2O.3Al_2O_3$ and $3CaO.2Na_2O.5Al_2O_3$ (point I) occurs at a composition 46.0 per cent CaO, 5.0 per cent Na_2O and 49.0 per cent Al_2O_3 and melts at 1420°.

Three quintuple invariant points were found in the system which are not eutectics, that is, they are invariant compositions at which three solid phases coexist with liquid and vapor occurring outside the triangle formed by the three solid phases.

The invariant point for $3CaO.Al_2O_3$, $5CaO.3Al_2O_3$ and $8CaO.Na_2O.3Al_2O_3$ (point J) occurs at a composition 46.5 per cent CaO, 4.5 per cent Na_2O and 49.0 per cent Al_2O_3. The melting temperature is 1423°.

The invariant point for CaO, $3CaO.Al_2O_3$ and $8CaO.Na_2O.3Al_2O_3$ (point M) occurs at a composition of 50.0 per cent CaO, 6.0 per cent Na_2O and 44.0 per cent Al_2O_3. The melting temperature is 1490°.

The invariant point for CaO, $8CaO.Na_2O.3Al_2O_3$ and solid solutions of $Na_2O.Al_2O_3 + 3CaO.2Na_2O.5Al_2O_3$ (point P) occurs at a composition of 42.5 per cent CaO, 13.0 per cent Na_2O and 44.5 per cent Al_2O_3. The melting temperature is 1475°.

In addition to the above, some evidence was obtained to indicate that an invariant point occurs along the boundary PI, which separates the fields of $8CaO.Na_2O.3Al_2O_3$ and solid solutions of $Na_2O.Al_2O_3$ with $3CaO.2Na_2O.5Al_2O_3$, in the neighborhood of point S. This would then represent the composition at which the $Na_2O.Al_2O_3$ had taken up its maximum of $CaO.Al_2O_3$ in solid solution and simultaneously was in equilibrium with $8CaO.Na_2O.3Al_2O_3$. It would thus be the origin of a boundary ST separating the field of $3CaO.2Na_2O.5Al_2O_3$ from that in which increasing percentages of $Na_2O.Al_2O_3$ are present in the primary phase.

THE BOUNDARY CURVES.

Many of the boundary curves shown in Fig. 1 are normal in all respects and need not be detailed. A few however are of especial interest.

At E a curve separating the fields of $5CaO.3Al_2O_3$ and $CaO.Al_2O_3$ leaves with temperatures increasing to point F, 1460°, which is a maximum. From F the temperature again drops to G, 1400°, the eutectic of $5CaO.3Al_2O_3$ and $CaO.Al_2O_3$. Thus the ternary eutectic E melts at a higher temperature (1430°) than the binary eutectic of $5CaO.3Al_2O_3$ and $CaO.Al_2O_3$ (1400°). It may be remarked that point F may be considered the point at which the boundary curve separating the fields of $5CaO.3Al_2O_3$ and $CaO.Al_2O_3$ enters the ternary diagram because $5CaO.3Al_2O_3$ does not exist as such in this ternary system but only as a solid solution of $5CaO.3Al_2O_3$ with the third component soda. Hence the binary eutectic to be considered in this case is not one of $CaO.Al_2O_3$ with pure $5CaO.3Al_2O_3$ but one of $CaO.Al_2O_3$ with the solid solution of $5CaO.3Al_2O_3 + Na_2O$ with a melting point of 1460° and falling at point F rather than point G.

From I the curve separating the fields of $8CaO.Na_2O.3Al_2O_3$ and $5CaO.3Al_2O_3$ leaves with temperatures increasing to point J, 1423°, the quintuple point at which $3CaO.Al_2O_3$, $8CaO.Na_2O.3Al_2O_3$ and $5CaO.3Al_2O_3$ are in equilibrium. The temperatures of melting of points I and J are so close as to be practically indistinguishable with the control available. Yet a little consideration will show that point I is the eutectic rather than J, for the eutectic composition must be within the triangle joining the compounds taking part in the eutectic melting. The three solid phases in equilibrium with liquid and vapor at J are $3CaO.Al_2O_3$, $8CaO.Na_2O.3Al_2O_3$ and $5CaO.3Al_2O_3$; but J lies in the triangle $5CaO.3Al_2O_3$-$8CaO.Na_2O.3Al_2O_3$-$3CaO.2Na_2O.5Al_2O_3$; hence it cannot be the eutectic. At point I, $5CaO.3Al_2O_3$, $8CaO.Na_2O.3Al_2O_3$ and $3CaO.2Na_2O.5Al_2O_3$ are in equilibrium with liquid and vapor, and since I lies in the triangle joining those compounds it must be the eutectic.

From J the boundary curve separating the field of $5CaO.3Al_2O_3$ from $3CaO.Al_2O_3$ leaves with temperatures increasing to a maximum at point K, 1435°, and then falling to L, the binary eutectic of $5CaO.3Al_2O_3$ and $3CaO.Al_2O_3$ at 1395°. This behavior is similar to that discussed above along the boundary curve E-F-G and is due to the existence of a solid solution of Na_2O in this system. Hence point K is the quadruple point at which $3CaO.Al_2O_3$ and solid solution $5CaO.3Al_2O_3 + Na_2O$ are at equilibrium with liquid and vapor, and from which the boundary curve separating the fields of crystallization enters the ternary diagram.

From M the boundary M-O leaves with temperatures increasing to O, 1508°, which is the maximum on the curve M-O-P separating the field of CaO and $8CaO.Na_2O.3Al_2O_3$.

Since O is the maximum on this curve, the compound which is dissociating must lie on a line joining O with the primary phase which separates when the compound dissociates. Inasmuch as O lies on the boundary separating the field of CaO from the field of $8CaO.Na_2O.3Al_2O_3$ the composition of the compound must lie on the line joining O with CaO. While the compound $8CaO.Na_2O.3Al_2O_3$ was never obtained as a perfectly homogeneous phase, yet it was in the neighborhood of this composition that the best samples of the compound were obtained. Final decision as to the composition was then made when the point O was located and O-CaO drawn.

From O the temperatures drop to point P, 1475°, the quintuple point at which CaO, $8CaO.Na_2O.3Al_2O_3$, and solid solutions of $Na_2O.Al_2O_3 + 3CaO.2Na_2O.5Al_2O_3$ are in equilibrium. The temperatures of melting then rise along the boundary separating the fields of CaO and $Na_2O.Al_2O_3$ to point Q, 1565° ± 10°, the binary eutectic of CaO and $Na_2O.Al_2O_3$.

From P the temperatures drop along the boundary separating the field of $8CaO.Na_2O.3Al_2O_3$ from the field of solid solutions of $Na_2O.Al_2O_3 + 3CaO.2Na_2O.5Al_2O_3$, towards S.

Point R represents the binary eutectic of $8CaO.Na_2O.3Al_2O_3$ with $3CaO.2Na_2O.5Al_2O_3$ which falls at 1465°. However, at S, melting occurs at a temperature of 1455°. At 1465° there are still two crystalline phases with liquid and vapor.

If $3CaO.2Na_2O.5Al_2O_3$ and $Na_2O.Al_2O_3$ form a continuous series of solid solutions, as seems probable, then melting might be characterized by a minimum such as found at 1455° in the region of point S. Until the system $3CaO.2Na_2O.5Al_2O_3$-$Na_2O.Al_2O_3$ is fully established, the boundary curve P—S—R must remain only partially explained.

THE BINARY SYSTEMS WITHIN THE TERNARY DIAGRAM.

The System $3CaO.5Al_2O_3$-$3CaO.2Na_2O.5Al_2O_3$. — These two compounds form a true binary system with a eutectic (point A) at a composition: 22.8 per cent CaO; 8.0 per cent Na_2O; 69.2 per cent Al_2O_3. This eutectic melts at 1550°. The unstable modification of $3CaO.5Al_2O_3$ appeared in some of the samples in this system but no definite region of stability of this modification was found.

The System $CaO.Al_2O_3$-$3CaO.2Na_2O.5Al_2O_3$.—The eutectic of these two compounds (point D) lies at a composition 30.3 per cent CaO; 5.4 per cent Na_2O; 64.3 per cent Al_2O_3. It melts at 1515°.

The System $5CaO.3Al_2O_3$-$3CaO.2Na_2O.5Al_2O_3$.—There is a eutectic formed in this system (point H) at a composition 40.4 per cent CaO; 4.3 per cent Na_2O; 55.3 per cent Al_2O_3. It melts at 1450°. The melting temperatures do not decrease regularly from the melting point of $5CaO.3Al_2O_3$ but increase from 1455°, the melting point of $5CaO.3Al_2O_3$, to 1480° when about 1 per cent of Na_2O is present. This increase is due to solid solution formation of soda, as previously described, in $5CaO.3Al_2O_3$.

The System $3CaO.2Na_2O.5Al_2O_3$-$Na_2O.Al_2O_3$.—No melting was observed in this system up to temperatures of 1630°. On examination of three samples in the system, a homogeneous phase was found with refractive indices which varied between those of $Na_2O.Al_2O_3$ and $3CaO.2Na_2O.5Al_2O_3$. These samples were plainly striated with an appearance somewhat as ex-solid solutions, i.e., crystalline material which existed as a solid solution at high temperatures but, due to reduced solubility at lower temperatures, separated into two phases on cooling. The X-ray patterns of these samples showed a structure similar but not identical to that of $3CaO.2Na_2O.5Al_2O_3$. The system cannot be defined with precision from the data at hand as equipment permitting the employment of higher temperatures is required. The correlation of all of the data indicate however that the system consists of a series of solid solutions of $CaO.Al_2O_3$ in $Na_2O.Al_2O_3$ with the end member at the composition $3CaO.2Na_2O.5Al_2O_3$.

The System CaO-$Na_2O.Al_2O_3$.—These two compounds form a true binary system with a eutectic (point Q) at 20 per cent CaO; 30 per cent Na_2O; and 50 per cent Al_2O_3. It melts at 1565° ± 10°. Samples of $Na_2O.Al_2O_3$ in this system are highly twinned; polysynthetic twinning is common.

Since the lines connecting the following compositions do not lie wholly within the fields of primary crystallization they do not form true binary systems. The following three systems are of that type:

The System $8CaO.Na_2O.3Al_2O_3$-$3CaO.2Na_2O.5Al_2O_3$ + $Na_2O.Al_2O_3$.—At the point (R) where the tie-line of the limiting composition of the solid solution series cuts the boundary separating the fields of primary crystallization, a eutectic appears to be formed having the composition: 43.7 per cent CaO; 10.2 per cent Na_2O; 46.1 per cent Al_2O_3. It melts at 1465°. $8CaO.Na_2O.3Al_2O_3$ appears along the liquidus in this system from the composition of the eutectic (R) to a composition U, 46.0 per cent CaO; 9.7 per cent Na_2O; 44.3 per cent Al_2O_3, where the tie-line joining the compounds intersects the boundary MP. On the lime side of that region, the $8CaO.Na_2O.3Al_2O_3$ dissociates into CaO and liquid; between R and $3CaO.2Na_2O.5Al_2O_3$ the latter compound is the primary phase.

This binary system may be regarded as extending from $8CaO.Na_2O.3Al_2O_3$ to any point on the line $3CaO.2Na_2O.5Al_2O_3$-$Na_2O.Al_2O_3$ but compositions along the line $8CaO.Na_2O.3Al_2O_3$-$Na_2O.Al_2O_3$ were not examined.

The System $5CaO.3Al_2O_3$-$8CaO.Na_2O.3Al_2O_3$.—The compound $8CaO.Na_2O.3Al_2O_3$ does not appear on the liquidus in this system.

The System $3CaO.Al_2O_3$-$8CaO.Na_2O.3Al_2O_3$.—In spite of the similarity in structure and habit of these compounds, no evidence of solid solution formation between them was found at the liquidus. The line joining these compositions merely represents one boundary of the limiting areas which determine the final products of crystallization in the adjacent triangles.

The systems CaO-$8CaO.Na_2O.3Al_2O_3$ and $Na_2O.Al_2O_3$ + $3CaO.2Na_2O.5Al_2O_3$-Al_2O_3 were not investigated.

THE COURSE OF CRYSTALLIZATION.

Three types of crystallization are found in this system. These will be discussed with the use of the diagram of Fig. 2, which shows only a part of the field.

1. The crystallization proceeds to a boundary curve along which one solid phase partially disappears while the other crystallizes, the process becoming complete at the quintuple point for that boundary curve. This type of crystallization may be represented by a composition at point a. The primary phase to separate on cooling a melt of that composition is $8CaO.Na_2O.3Al_2O_3$. As that compound separates, the composition of the liquid follows the line a b. When b is reached, $3CaO.2Na_2O.5Al_2O_3$ appears with the $8CaO.Na_2O.3Al_2O_3$. Those two phases separate together, the mean composition of the solid following the line $8CaO.Na_2O.3Al_2O_3$-$3CaO.2Na_2O$.

$5Al_2O_3$ and that of the liquid following the line b I. When I is reached, the mean composition of the solid phase is represented by point c. $5CaO.3Al_2O_3$ then separates with the other crystalline phases and the mean composition of the solid phase follows the line c a, ending at a.

2. The crystallization curve proceeds to a quintuple point but at that point one solid phase entirely disappears and the crystallization curve proceeds along a boundary to another quintuple point. The primary phase at point d is CaO which separates until the liquid reaches the composition e. Tricalcium aluminate then crystallizes with CaO along the line CaO-$3CaO.Al_2O_3$ until the mean composition of the solid phases arrives at point f when the composition of the liquid will be at M. $8CaO.Na_2O.3Al_2O_3$ then appears and the composition of the solid phase follows the line f g while the liquid remains at M. When the mean composition of the solid phases is represented by point g, the CaO disappears, having been

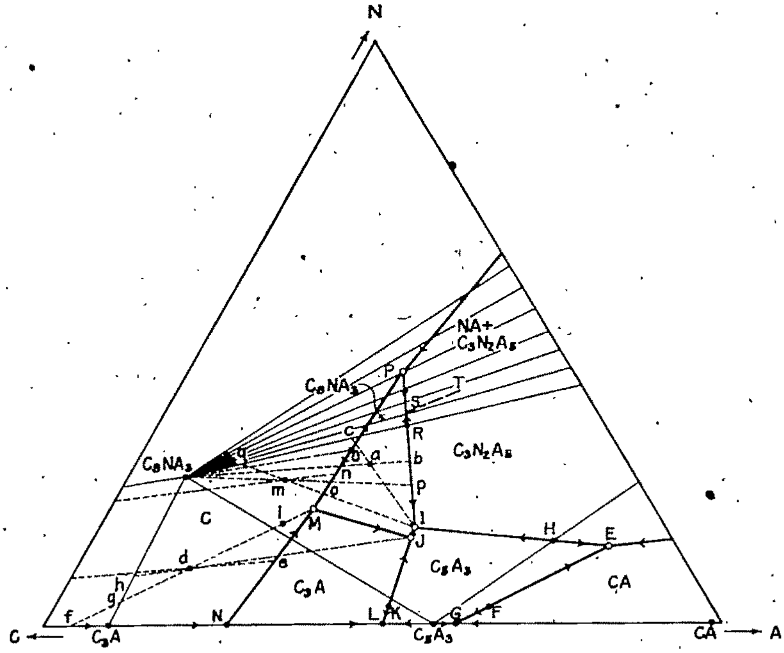

Fig. 2—Diagram Showing Course of Crystallization in a Part of the System $CaO-Na_2O-Al_2O_3$

dissolved during the simultaneous crystallization of $3CaO.Al_2O_3$ and $8CaO.Na_2O.3Al_2O_3$. The mean composition of the solid then follows the line g h while the liquid changes from M to J. At J, $5CaO.3Al_2O_3$ appears and the composition of the solid follows the line h d, and ends at d.

If the original composition had been located within a restricted area above the line connecting $8CaO.Na_2O.3Al_2O_3$ and $5CaO.3Al_2O_3$, as at i, the crystallization curve would not have ended at J, but would have proceeded to the ternary eutectic at I.

3. The crystallization curve proceeds to a boundary along which one solid phase entirely disappears before a quintuple point is reached; it then leaves the boundary and crosses a field to another boundary curve along which it proceeds to a quintuple point. The primary phase at point m is CaO which separates until the liquid has the composition of point n. $8CaO.Na_2O.3Al_2O_3$ then appears and the mean composition of the solid phase passes along the line connecting CaO and $8CaO.Na_2O.3Al_2O_3$ until the composition of $8CaO.Na_2O.3Al_2O_3$ is reached. The liquid then has the composition of point o. On further cooling, $8CaO.Na_2O.3Al_2O_3$ separates alone while the composition of the liquid changes from o to p. At p, $3CaO.2Na_2O.5Al_2O_3$ appears and the mean composition of the solid changes from $8CaO.Na_2O.3Al_2O_3$ to point q while the liquid follows p I to I. At I, $5CaO.3Al_2O_3$ appears and the mean composition of the solid changes from q to m, where the crystallization ends.

THE SIGNIFICANCE OF THE SYSTEM
CaO-Na_2O-Al_2O_3
IN PORTLAND CEMENT.

As stated in the introduction of this paper, that portion of the CaO-Na_2O-Al_2O_3 system in the neighborhood of $3CaO.Al_2O_3$ and low in soda is the region which is directly concerned with portland cement. From this work alone however we cannot predict the combinations of soda in cement; to do so a study must be made of systems involving the other components of cement with soda. However, we are able to say the following: Of the compounds of CaO, Na_2O and Al_2O_3 which are important in solving the final status of the Na_2O in cement, $8CaO.Na_2O.3Al_2O_3$ alone is of significance. This is due to the existence in portland cement of $3CaO.Al_2O_3$ alone, of the compounds of lime and alumina, and the finding in this study that the field of $3CaO.Al_2O_3$ adjoins that of $8CaO.Na_2O.3Al_2O_3$ but not that of $3CaO.2Na_2O.5Al_2O_3$. The stability of $8CaO.Na_2O.3Al_2O_3$ with the other constituents of cement, $3CaO.SiO_2$, $2CaO.SiO_2$, $4CaO.Al_2O_3.Fe_2O_3$ and MgO, must therefore be determined before the composition of the compounds of soda in cements can be defined.

Any direct attempt to identify $8CaO.Na_2O.3Al_2O_3$ in a commercial or laboratory cement probably would be unsuccessful. Identification by the microscope would be extremely difficult since the compound must necessarly be present only in small amounts and the similarity of optical properties of $8CaO.Na_2O.3Al_2O_3$ and the other cement compounds makes difficult its differentiation from them by microscopic means. Likewise, the X-ray method cannot be used to advantage because the principal lines of the diffraction pattern of $8CaO.Na_2O.3Al_2O_3$ coincide with those of $3CaO.Al_2O_3$ and only if $8CaO.Na_2O.3Al_2O_3$ were present in excessive amounts could we hope to establish its presence in cements. Hence thermal studies alone furnish the basis for establishing the nature of the soda compounds in cement. If thermal studies show that $8CaO.Na_2O.3Al_2O_3$ is stable in the presence of $3CaO.SiO_2$, $2CaO.SiO_2$, $4CaO.Al_2O_3.Fe_2O_3$ and MgO, we are assured that Na_2O may exist in cement in the form of that ternary compound. In that case the Na_2O may replace some of the CaO from $3CaO.Al_2O_3$ and form the new combination, $8CaO.Na_2O.3Al_2O_3$. Former studies in this laboratory have indicated that Na_2O replaces CaO when the former is added to cement compositions but this does not necessarily mean that the replacement must be in $3CaO.Al_2O_3$. It might be a replacement in $4CaO.Al_2O_3.Fe_2O_3$ or the silicates. All of these questions can be solved only by further study of the soda systems with the other components of cement.

SUMMARY.

A part of the system $CaO\text{-}Na_2O\text{-}Al_2O_3$ has been investigated by the method of phase equilibria and the results presented.

Two ternary compounds were found in the system, having the compositions: $3CaO.2Na_2O.5Al_2O_3$ and $8CaO.Na_2O.3Al_2O_3$.

The stability fields of the phases in the system have been defined, the boundary curves indicated and the invariant points located. The compositions and melting points of the compounds and of the invariant points are summarized in Table X. The optical properties of the ternary compounds and of $Na_2O.Al_2O_3$ and βAl_2O_3 are given in Table XI. The interplaner spacings of the X-ray diffraction patterns are listed for the ternary compounds and for the binary compounds which have not previously been reported. Diagrams are presented which indicate the stability fields, temperature relations and course of crystallization in the system.

ACKNOWLEDGMENTS.

The authors gratefully acknowledge their indebtedness to Dr. W. C. Hansen, formerly of this Staff, for his contributions to this study. The investigation was begun by Dr. Hansen and brought by him to partial completion in the region of the compound $3CaO.2Na_2O.5Al_2O_3$. Both for his important contribution and for Dr. Hansen's continued interest and advice in the final solution of the system the authors take pleasure in giving full recognition and thanks.

TABLE X. Compositions and Melting Points.

Composition	CaO	Na_2O	Al_2O_3	M. P.	Authority
		Compounds			
C_3A	62.2	...	37.3	1535*	Rankin, et al.
C_5A_3	47.8	...	52.2	1455	"
CA	35.4	...	64.5	1600	"
C_3A_5	24.8	....	75.2	1720	"
NA	...	37.8	62.2	1650	Matignon
$C_3N_2A_5$	20.9	15.5	63.6	>1630	Brownmiller
C_4NA_3	54.9	7.6	37.5	1508*	"
		Binary Eutectics			
C_3A-C_5A_3	50	...	50	1395	Rankin, et al.
C_5A_3-CA	47	...	53	1400	"
CA-C_3A_5	33.5	...	66.5	1590	"
C_3A_5-A	24	...	76	1700	"
C-NA	20	30	50	1565	Brownmiller
$C_3N_2A_5$-C_3A_5	23	8	69	1550	"
$C_3N_2A_5$-CA	30.5	5	64.5	1515	"
$C_3N_2A_5$-C_5A_3	40	4.5	55.5	1450	"
$C_3N_2A_5$-C_4NA_3	43.2	10.3	45.5	1465	"
		Quadruple points not eutectics			
C-C_3A	57	...	43	1535	Rankin, et al.
C-C_4NA_3	46.8	9	44.2	1508	Brownmiller

* Dissociation temperatures.

		Ternary Eutectics			
C_3A_5-CA-$C_3N_2A_5$	27.5	6	66.5	1465	Brownmiller
CA-C_5A_3-$C_3N_2A_5$	38	4	58	1430	"
C_5A_3-C_8NA_3-$C_3N_2A_5$	46	5	49	1420	"
		Quintuple points not eutectics			
C_5A_3-C_3A-C_8NA_3	46.5	4.5	49	1423	Brownmiller
C_3A-C-C_8NA_3	50	6	44	1490	"
C-C_8NA_3-$C_3N_2A_5$+NA ...	42.5	13	44.5	1475	"

TABLE XI. Optical Properties of Some of the Compounds Examined.

Refractive indices, ± .003	Optic axial angle	Character	Appearance
NA $\alpha = 1.566$; $\beta = 1.575$; $\gamma = 1.580$	About 30°	Biaxial negative	Colorless, rounded grains; twinning common
βAl_2O_3 $\omega = 1.678$; $\epsilon = 1.635$	Optic axis parallel to c-crystallographic axis	Uniaxial negative	Plates; hexagonal system
$C_3N_2A_5$ Mean index 1.592; weak birefraction	....	Biaxial positive	Rounded grains
C_8NA_3 $\alpha = 1.702$; $\gamma = 1.710$	Medium angle	Biaxial negative	Polyhedrons with hexagonal or octagonal outline

The authors are indebted also to Dr. Herbert Insley of the Bureau of Standards who gave assistance in the microscopical identification of the phases, and to Dr. Frank C. Kracek of the Geophysical Laboratory for his advice and suggestions in the interpretation of data.

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BUREAU OF STANDARDS,
WASHINGTON, D. C.

A NEW TRIASSIC AREA IN NORTH CAROLINA.

CARL B. BROWN.

INTRODUCTION.

An hitherto unreported outlier of Triassic deposits has recently come to light in North Carolina through the operations of the United States Bureau of Chemistry and Soils. Although its presence is noted in the soils report for Davie County,[1] it has not yet been described or brought to general attention. The writer was able to spend parts of two days in the area recently, and the general characteristics noted at that time are presented below.

The Triassic basin is located in the northwestern corner of Davie County, North Carolina, eight miles northwest of Mocksville. It lies for the most part along the upper course of Dutchman's Creek, and just west of State Highway No. 80. Its geological boundaries approximately coincide with those mapped for its soil derivative, the Granville fine sandy loam. The total area of the outlier is a little over eight square miles.

SEDIMENTS.

The sedimentary beds consist of buff to red conglomerates, coarse to fine, white, buff, pink, and red sandstones, and buff to red shales. The basal beds are most clearly shown along the eastern margin on the banks of Chinquapin Creek and Howard's Branch. These are conglomerates which vary in hue from buff to dark red, the prevailing cast being subject to the color of the matrix. The darker colored beds are generally hard and indurated, and yield a clean smooth fracture across pebble and matrix alike. The lighter colored beds contain more arkosic material and are less firm. Pebbles in these beds have an average size of one to two inches, but those of six inch diameter are very common while one foot is a maximum. The pebbles consist of granite, granite gneiss, hornblende gneiss, chlorite and other schists and vein quartz. All of these rock types are found in the immediate vicinity. It is not possible to give accurately the thickness of the basal conglomerate, for no section across it could be found, but it is estimated at 75 feet.

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[1] Jurney, R. C., and Bacon, S. R., Soil Survey of Davie County, N. C.; Bureau of Chemistry and Soils, U. S. Dept. of Agriculture, Series 1927, No. 5.

Sandstones and shales make up the bulk of the sediments. These are gradational in all proportions. Much of the coarse sandstone is conglomeratic. The pebbles are distributed irregularly and in thin horizons or bands. Occasionally a true conglomerate bed is intercalated, which may range in thickness up to 12 feet. The coarser sandstones are generally pink or buff. Frequently they are highly arkosic, especially in the lower part of the series just above the basal beds. In these overlying arkoses large fragments of silicified wood were found, and in one instance, in finer-grained beds, partly lignitized wood. Specimens weighing up to 20 pounds were collected.

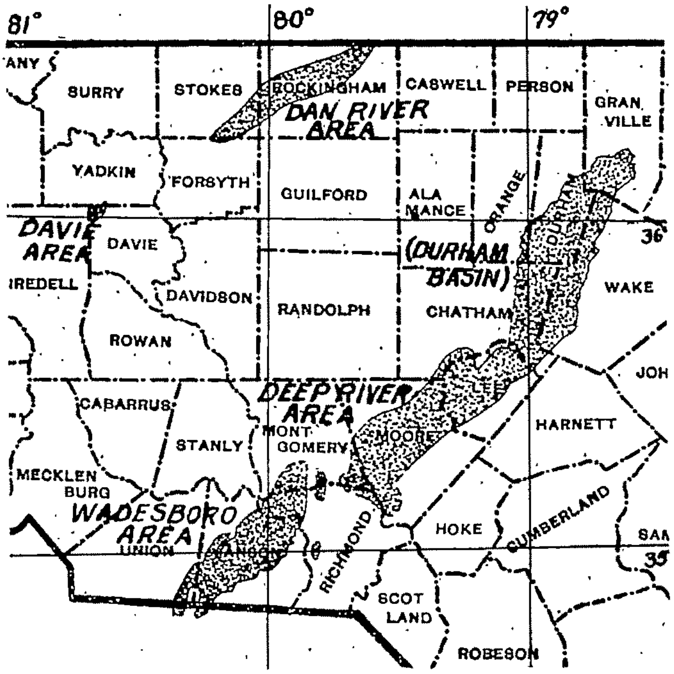

Fig. 1. Map showing the relation of Davie County area to other Triassic areas in North Carolina.

Red shales occur but are not abundant. Massive red mudstones and white clays are also present in the sequence. Sandstones are, however, the most prevalent type. The nature of the cross-bedding in certain layers, the irregular distribution of beds, and the character of the sediments indicate fluvial waters as the dominant agent of deposition.

IGNEOUS ROCKS.

Diabase dikes are both common and large. The width of outcrop frequently exceeds 200 feet, though it is possible that certain of the larger bodies may be sills. The largest of the dikes seem to be intruded along border fault zones. This is especially apparent along the western margin on the roads south and west of Cook's School. The diabase appears megascopically to be typical of the smaller trap dikes of the Piedmont. In several spots baked shales were noted, and at one place a fragment of silicified wood found on the surface was blackened and indurated, apparently from an adjacent trap dike.

STRUCTURE.

The structural pattern of this outlier is complicated by three or more sets of intersecting faults, trending in general northeast, north, and northwest. The numerous faults in combination with the relative thinness of the series has made a surface pattern of unusual shape, as seen in Fig. 2. The southeastern border is the normal expression of the unconformity

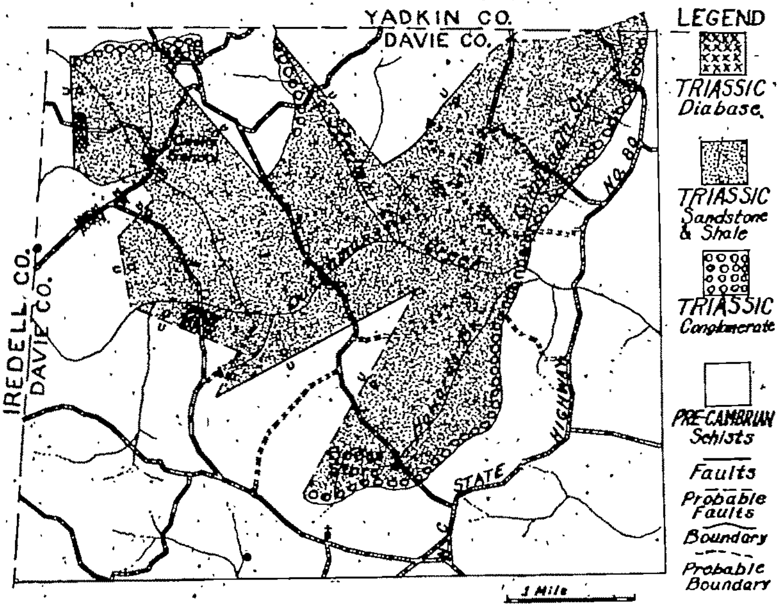

Fig. 2. Geological map of Davie County Triassic area,

between Triassic above and crystallines below. On the road north from Booe's Store an area of chlorite schist is crossed, and on its north side is an observable fault. This body of schist is interpreted as part of an upfaulted "wedge." Certain of the other faults are reasonably definite, while the remainder are shown by dash lines as hypothetical. All dips noted were toward the northwest, although the strike varied within 20°. Dips are unusually high compared to those of other Triassic areas. Inclinations of 45° to 60° are common near the southeastern border, and at one place as much as 80° was noted. The dips are somewhat flatter toward the northwest, but nearly always exceed 25°. Several small faults were seen within the basin, and along one of these heat of friction during slippage had indurated the sandstone for about two inches.

This new area is particularly interesting and significant because it lies in a direct line of strike with the Dan River Triassic area which ends at Germanton, in Stokes County. The interval between the two areas is approximately 25 miles. It seems probable that the Davie area lies along the same fault zone that accounts for the preservation of the Dan River area.

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DISCUSSION AND COMMUNICATIONS.

THE EVOLUTION OF THE CLASS INSECTA.

My good friend Professor Charles Schuchert very kindly arranged for the publication of a critical symposium on a recent paper entitled "The Evolution of the Class Insecta" (Proc. Roy. Soc. Tasmania, 1930, pp. 1-89) which was an amplification of a Presidential Address which I delivered at the biennial meeting of the A. N. Z. A. S. in Brisbane in 1930. For this I desire to express to him my very sincere thanks. The contributors to this symposium were Dr. F. M. Carpenter, Professor Percy E. Raymond and Professor Alexander Petrunkevitch; the first named writing from the point of view of a paleo-entomologist, the second from that of a student of Paleozoic Crustacea, and the third from that of a student of living and fossil Arachnids. The result of their efforts is now before me, in the publication issued in this Journal, June, 1931 (21, 531-539). I now request the privilege of replying to them, and I propose to deal with their contributions in the inverse order to that in which they were published.

(1) *Professor Petrunkevitch's Criticisms.*

Professor Petrunkevitch's contribution is the shortest of the three, yet I find in it more of value, and more lasting food for thought, than in the other two, and I feel grateful to the talented author for bringing out so clearly one of the basic ideas underlying my new theory. He says:

"Unfortunately, though naturally, in discussing segmentation, Tillyard follows the usual method of homologizing segments in accordance with their numerical position relative to the first cephalic segment. Is this principle correct?" And he proceeds to the statement that the method could not be applied to the vertebrates, and that, in the arthropods, there is the added difficulty sometimes of having to decide what *is*, and what *is not*, a true segment. This is all readily admitted by me, and I hope that Petrunkevitch will admit, on his part, that my treatment of the head and body segmentation in the paper under discussion does actually constitute a departure from the usual method, though perhaps not such a complete breakaway as he would apparently desire. I think this point can be most clearly appreciated if he would look again at my Table C (p. 41) where I give the results of my analysis of the segmentation in the ontogenetic stages of the Pauropoda. Allowing five segments for the head (the actual number in the head matters little in this illustration), it will be seen that the preanal segment of the hexapod larva is the *tenth* from the anterior end of the animal if we count in the usual manner. In the ten-legged larval stage, it is the *twelfth* segment; in the twelve-legged larval stage, it is the *thirteenth;* in the sixteen-legged larval stage, it is the *fifteenth* segment; and, finally, in the adult Pauropod, it is the *sixteenth* segment! Yet there surely cannot be any doubt that it is the same segment throughout, and, if we count from the posterior end, it remains throughout the penultimate segment!

Thus, in the ontogeny of any animal which undergoes anamorphic development, the original rule is broken immediately. In the case of an animal in which there are two "zones of addition," e. g. the *Nauplius,* where there are segments added not only at the hinder end of the animal but also behind the mandibular segment, the position becomes even more patent.

Now, unless we are going, like De Beer, to jettison all belief in the Biogenetic Law, we must surely admit that this principle must also apply to phylogeny. In other words, if we had before us a Pauropod and the ancestral form from which it came, millions of years ago, we *could not* logically homologize the segments of these two animals by counting from the anterior end. *A fortiori,* since Arthropoda in general must surely have diverged far more, both in segmentation and in other characters, between themselves, in order to arrive at their present-day complexity of forms, it follows that the usual method cannot be defended, and Petrunkevitch's criticism is sound in so far as my work shows any appearance of having attempted to do so. But I wish to assure Petrunkevitch that I am as convinced as he is in this matter, and that, if my arguments appear otherwise to him, it is only because of the necessity of adopting *some* definite method of exhibiting one's comparative results. If Petrunkevitch will again read what I have said about the *Nauplius* and the "nauplioid ancestor" on p. 42, followed by the argument on pp. 43-46, he will, I feel sure, admit that, while compelled to use numerical homologies in my Tables in order to exhibit my results, I have also been striving to express the same belief as he himself, by emphasizing, I believe for the first time in any theory of the evolution of the Insecta, the great importance of the three types of segmentation, and, in particular, the significance of anamorphosis. Indeed, Petrunkevitch, speaking of this point, says that my recognition of the three types of postcephalic segmentation is "well grounded." I am quite willing to admit that my study of the head segmentation does not yield so good a result; for here comes in that difficulty which Petrunkevitch sees so clearly, viz. the difficulty of deciding what *is,* or what *is not,* a segment. The intercalary segment in insects is, I imagine, a case in point, though modern authors almost unanimously accept it as homologous with the second antennal segment of Crustacea. The problem of the maxillulae is an even greater difficulty, and one notes that the opinions of Hansen and Crampton on this matter are still as far apart as ever they were.

Petrunkevitch, of course, speaks from the point of view of an expert in the Arachnida, a group which most entomologists neglect very badly. I have to confess that I do not know how many segments there really are in the head of a scorpion, and I doubt if any entomologist knows either. The evidence at my disposal did not appear to make it safe for me to suggest more than four; but, if Petrunkevitch has proved that there are eight, I will accept that number. I should like to know whether Petrunkevitch would agree that the *mandibular segment* could safely be homologized in the four groups of Trilobita, Crustacea, Myriapoda (*s. lat.*) and Insecta and whether, in that case, he could indicate with certainty which segment of the arachnid head was its homologue? It seems to me that the segment of the pedipalps is more likely to be so than that of the chelicerae, or, indeed, any other. But I am open to further argument on this point.

The truth is that, for the correct interpretation of the ontogenies, we need a sufficiently complete fossil record of the phylogenies of the different classes. That cannot be obtained until we are able to explore far back into the pre-Cambrian, where I have evidence leading me to believe that primitive arthropods with separate head segments are to be found. This evidence will be published shortly.

The criticism made about the Tardigrada and other groups lies outside the main argument, but should, I think, be answered. It all depends on the definition given to the phylum Arthropoda, as to what groups fall into it, or outside it. Nature did not make the arthropods as a phylum; she made them as they are, and it is left to the individual student to classify them. So I do not see why the inclusion of the Tardigrades in the Arthropoda, or the Pycnogonida or Xiphosura in the Arachnica, is "unfortunate"; it is only "not according to Petrunkevitch's views." Was Ray Lankester "unfortunate" in writing his classical paper "Limulus an Arachnid"? I trow not!

The Tardigrada are hard to place in any logical system. But they are certainly arthropodan in the structure of their legs, which are movable upon the body-segment and end in a claw. Where else, except in the Arthropoda, does this character occur? Thus, in dealing with this character, I feel justified in placing them with the Arthropoda, whatever I may think about them on other points.

In his last paragraph, Petrunkevitch demands a "new principle underlying homologous structures and segmentation in Arthropods" as an essential before we can unravel their evolution. I can agree with this fully. My belief is that a thorough study of the phenomenon of anamorphosis, which has never yet been attempted, might well help to disclose this "new principle" to us. The "new principle" itself might very well, in the sequel, prove to be based upon some amount of recognition of *tagmata* as essential units in phylogeny as well as single body-segments. To illustrate what I mean:—An antenna, for example, is always considered as a single organ or unit, though the number of segments in it may differ very greatly in the different stages of a single ontogeny. The only way to homologize the segments of such an organ in successive instars is to put on record their actual anamorphic development, i.e. how segment 7, for example, has been derived by subdivision from a more original segment 6, and so on. Now the same type of development occurs ***in the body-segments,*** e.g. in the ontogeny of *Pauropus*. Therefore the abdomen of *Pauropus* has just as much right to be considered a single unit or *tagma* as a segmented leg or antenna has. Once this principle is recognized as valid ***in phylogeny*** as well as in ontogeny, our aim will have been attained. One of the chief objects of my paper was to stimulate new thought and new researches along such lines as these, and I am very grateful to Petrunkevitch for supporting my point of view.

(2) *Professor Raymond's Criticisms.*

We turn now to the article written by Professor Raymond from the point of view of a student of Paleozoic Crustacea. Knowing that Raymond's chief interest and studies lie in the great fossil group of the Trilobites, one naturally expects that he would center his attention on my treatment of Handlirsch's theory, and one is not disappointed. I am therefore greatly relieved, and not a little encouraged, to find that Raymond shares my opinion of this famous theory, except that I "show a much more sympathetic attitude to it than can be achieved by the present writer." The task that I set myself was to present Handlirsch's theory to my readers ***in an absolutely fair setting,*** in spite of my basic disagreement with it, and I have Handlirsch's word for it that I succeeded! That I managed to achieve the same objective with a much more difficult theory, that of Crampton, is also very encouraging to me.

Concerning the figure of a Trilobite, shown on p. 6, fig. 1, of my paper, Raymond says:—"He [Tillyard] has produced, with attribution to Beecher, an extremely inaccurate figure of a trilobite showing sternites and appendages, constructed apparently by combining the observations of Beecher with the somewhat fanciful deductions of Jaekel." Raymond will be interested to learn that I ***constructed*** this figure simply by taking Handlirsch's original figure in Schröder's "Handbuch der Entomologie," Bd. III, p. 334, and sending it to the block-maker, who faithfully reproduced it in my paper! So careful was I to present Handlirsch's theory intact, that I felt it essential to show his own figures of a trilobite, a paleodictyopteron and its hypothetical larval type, ***without any alterations;*** these can be found in my figs. 1-3. The only error that I made was in the legend of fig. 1, which should have read "Reconstruction by Handlirsch, partly after Beecher." In his "Die fossilen Insekten," p. 1303, Handlirsch actually made use of Beecher's figure, which was also the figure which I used in my lecture in Brisbane. It was just the unfortunate fact that I could not send this ponderous tome to the printers in Sydney, which caused me to turn to my unbound copy of Schröder's "Handbuch," where I detached p. 334 and the other pages containing figs. 2-3, for the printer's use, and unfortunately failed to note the altered legend beneath. By comparing the two figures given by Handlirsch, one can see at once that the second one is founded partly on Beecher's famous figure, with additions in the mid-ventral region which Raymond asserts are sternites, but which Handlirsch does not discuss in his text. I agree with Raymond that the figure is inaccurate, and I hinted as much, on p. 11, where I called attention to the fact that Handlirsch did not indicate the limits of the pygidium. About the alleged "sternites" I kept silence, because I could not find in Handlirsch's text any allusion to them.

I accept Raymond's correction of my misunderstanding of the nature of the modifications as between pygidium and thorax. On the evidence of the *Protaspis* larva, an early stage with large cephalon and large pygidium begins the ontogeny, and segments are "freed from the anterior margin of the pygidium to form the thorax." But, may I ask, is Raymond quite sure that this actually happened also in the phylogeny of the group, as in the ontogeny of the individual? If so, he is a supporter of the Biogenetic Law, as I am. Then, to me, it seems rather strange that the insects should have had to pass through the following phylogenetic stages: (a) an early trilobite ancestor with a compound pygidium, (b) a later trilobite ancestor with a simple or "broken-down" pygidium, (c) a rebuilding of lost segments by anamorphosis! Would it not be nearer the truth to hold that the transference of subsegments from the pygidium, to become full segments of the thorax, is a close analogue of the process of anamorphosis in the myriapod-insectan ancestor, and that therefore, right through the phylogeny, the marine and the terrestrial groups have proceeded side by side rather than from one to the other? But how can Raymond, in any case, harmonize the two statements (a) "Such a trilobite may have been in the ancestral line of the insects" (p. 536) and (b) "Tillyard shows, in fact, a much more sympathetic attitude towards it (i.e. Handlirsch's theory) than can be achieved by the present writer." If he does not believe in the argument adduced by him in (a), why put it in?

On p. 537, Raymond writes: "To state, however, that the head of the primitive crustacean had only four segments is to pass *entirely* into the realm of theory." I stress the word "entirely." So then, the presence of a four-segmented *Nauplius* head in the ontogeny of Crustacea ***has no phylogenetic significance!*** Yet the form of the *Protaspis* has ***immense*** phyletic significance! Why apply the Biogenetic Law to one larval form, just because it is the larva of an ancient fossil type, and refuse to apply it to another because it is a living form? In opposition to Raymond, I maintain that the structure of the *Nauplius* head *has* phylogenetic significance, and I assert that there must have existed arthropods in pre-Cambrian times in which the head was certainly only four-segmented. So, then, if the *Protaspis* had six head-segments, and the *Nauplius* only four, then, *in this character only*—not necessarily in any other—the *Nauplius* must be adjudged the more primitive, just as the living stalked crinoid of to-day must be adjudged more primitive, *in the character of the stalk,* than many an ancient sessile type. However, one of the reasons why I introduced the "nauplioid ancestor" was to destroy as effectively as possible the old fetish about the mystic number twenty-one (or is it twenty-two?) in arthropod segmentation, and I am very glad to find that Raymond is heartily with me in this.

As regards my argument from the second antennae, I am glad to find that Raymond (p. 537) admits that "this objection has real force if an attempt is made to derive the insects from any of the modern crustaceans." It is something gained if Crampton has at last been driven from this untenable position, and now takes refuge in an attempt to derive insects from "Crustaceoid ancestors." Hansen, on the other hand, sticks close to his guns, and still insists that the Insecta have a seven-segmented head exactly homologous with the head of the Amphipoda and Isopoda; or, in other words, that the labium or second maxillae of insects is the homologue of the first pair of maxillipedes of these Crustacea. And necessarily, therefore, he must claim a derivation of insects from the common stem of Amphipoda and Isopoda, at a date late enough for this seven-segmented head to have been already developed! It is, of course, unfortunate for Hansen's argument that it happens to be the *first* antennae, not the second, which undergo reduction so frequently in this particular group or groups, e.g. in the terrestrial Oniscoidea. But this position is reversed in some of the more primitive groups, e.g. in the Notostraca, where the antennules or first antennae may be entirely missing, as in some species of *Apus.* Raymond's argument is thus seen to be very apt and to the point. One might, perhaps, be allowed to comment on the fact that it is Crampton who has given Hansen the severest blows of all; though, in his latest work, the doughty Dane comes up smiling once again, and gives back a Roland for every Oliver. It is clear that they cannot both be right; yet until the problem of the maxillulae is finally settled, what hope is there of the acceptance of *any* theory of crustacean origin for insects?

At this point, I feel very much like the curate in the middle of eating his famous egg. Having just tasted a nice bit, I now bite upon a very nasty one! It concerns the evidence for the existence of originally biramous limbs in the Insecta. Raymond says (p. 538):

"According to Tothill, the rudiments of the first and second maxillae of the embryos of insects are bifurcated, and may indicate that these appendages at least were probably biramous in the ancestor of the insects." Reference should be made here to Tothill's actual words, (this Journal, 42, 1916, p. 379), as follows: "The rudiments of the maxillae in insects are characteristically paired on each side and possibly indicate a biramous condition of all the ancestral appendages. The evidence, however, only points directly to the biramous condition of the first and second maxillae."

From these quotations, one is bound to gather that both Tothill and Raymond believe that there is here definite evidence that the maxillae of insects were originally biramous appendages. Or, to be more precise, they believe that the "paired" condition of these appendages in the embryos of some insects is a repetition, in the ontogeny, of a primitive phylogenetic condition in which the maxillae possessed both endopodite and exopodite.

Now Hansen showed, more than twenty-five years ago, and Crampton has also stressed the point, that the maxillae of insects *do not possess an exopodite at all.* There is no need for me to make specific quotations here, for the matter is one of common knowledge. The bilobed, or sometimes even trilobed, nature of the maxillary rudiments is very easily explained. If any of my critics would take the trouble to watch, as I have done, the development of the maxillary rudiments up to the time of hatching of the egg, they would at once admit the accuracy of my statement. The maxillary rudiment in an insect embryo *very early takes the form which it is destined to possess in the young larva.* Thus, in *Lepisma,* it soon assumes a trilobed form, which is due to the early formation of the two gnathobases (lacinia and galea in the first maxilla), and has nothing whatever to do with any primitive biramous condition, Reference might here be made by Raymond to Tothill's fig. 1A, p. 375, and I might ask him why he ignored this piece of evidence from this very paper? For, surely, he would not argue that the maxillae were originally *triramous!* But let me offer an even more striking example. In the Odonata, there is a contrast between the forms of the rudiments of the first and second maxillae. That of the first maxilla early takes a *bilobed* form, and this form can be easily followed out in the growing embryo, until it appears, at hatching, as a larval first maxilla with simple palp (*endopodite*) and undivided *inner lobe* consisting of combined galea and lacinia. On the other hand, the rudiments of the second maxillae retain the form of a pair of embryonic legs, without any lobes; and these, at hatching, fuse together to form the *labial mask,* in which the gnathobases have been suppressed! Could anything be more eloquent of the true nature of the "paired" condition in the rudiments of these organs?

Let me repeat that I am not doing anything more than to ask for clear-cut evidence, *from within the Insecta as a class,* for the derivation of *any* insectan appendage from one of the biramous crustacean type, i.e. one having both endopodite and exopodite.

I am not absolutely opposed to such an idea at all; but I must insist that attention should be paid to more promising lines of research, such as the true nature of the coxal styles in Machilidae and of the divided gonopods in many primitive insects. If either of these could be *proved* to be structures carried over unchanged from a crustacean type, rather than specializations developed within the class Insecta, progress would have been made. But, so far, I have failed to find, either in the styles or in the gonopods or anywhere else, any clear evidence to this effect.

Let me now turn to another argument used by Raymond which, to my mind, appears forced. I refer to his remarks on the nature of the Devonian fossil genus *Rhyniella* (p. 536). Raymond questions my determination of this animal as a Collembolon, in the following words:

"The material is very scanty, Tillyard himself stating that only two specimens are of importance, a fragment of a head showing an antenna 0.254 mm. long, and a minute pair of mandibles. His determination is based almost entirely on the former. The Rhynie chert has produced thousands of fragments of a little crustacean which was described by Scourfield. It seems rather a remarkable coincidence that the antennae of this little creature, *Lepidocaris rhyniensis,* should be so similar to those of the 'insect.' "

Now the facts are these:—Out of about 2,000 chips and sections examined by Scourfield, to use his own words (Phil. Trans. Roy. Soc., B **104**, p. 155), "not more than a quarter . . . . have yielded traces of animals of any kind, and of these not more than about one in five has proved of any value in the work . . ." Thus the total number of fragments is about a hundred, not "thousands" as Raymond states. Two specimens are placed by me as Collembola. But Scourfield searched the whole field of chips for *Lepidocaris,* whereas I only studied Hirst and Maulik's two accidental specimens of *Rhyniella.* Now that Scourfield has also searched for *Rhyniella,* quite a number of specimens have turned up, and he now has almost the whole animal, including head, thorax, legs and part of the abdomen! Through his courtesy, I have been enabled to study drawings of these new specimens, and there is no doubt that they are true Collembola. Professor Handschin, the eminent Swiss expert on the Collembola, has also seen them, and gives it as his opinion that *Rhyniella* can actually be classified in the modern subfamily Hypogastrurinae.

Further, if Raymond will again look up Scourfield's monograph on *Lepidocaris,* he will discover that the antennae of that little crustacean were not, as he has stated, three-jointed, but were large, biramous organs, having ***a basal portion*** of three short joints, an ***outer branch*** of five joints with long plumose setae, and an ***inner branch*** of two joints; they were also about three times as long as the antennae of *Rhyniella,* which they do not resemble in the slightest. If, now, Raymond replies that he made an error in the use of the word "antennae," and that he intended to say "antennules," then my reply is that even these short, three-segmented organs in no wise resemble the antennae of *Rhyniella,* nor are they inserted in anywhere near the same position on the head!

No, I am afraid that Raymond, no less than Handlirsch, will be compelled to accept *Rhyniella* as a true Collembolon, and to adjust his views of insect evolution accordingly.

(3) *Dr. Carpenter's Criticisms.*

It is apparent, from Carpenter's remarks, that, however carefully he may have read my paper, he has not gained the slightest understanding of it. No exception can be taken to the first page of his remarks, in which he briefly traverses my accounts of the principal existing theories. But, as soon as he tries to interpret my own theory, he goes right off the mark. By stressing many of the less important points, and entirely ignoring those on which the theory is actually based (e.g. the study of the three modes of segmentation), he arrives at the following analysis of my theory (p. 533):

"Briefly, then, Tillyard's theory is that the Pterygota have been descended from the Apterygota, the lowest form of which is the Collembola-type; the Collembola stock have been derived from the progenitor of the chilopods; and this progenitor is a development of the ancestor of the diplopods. The common ancestor of the Diplopoda, Chilopoda, and Insecta, Tillyard calls the 'Protaptera'."

This is my theory "expressed in its lowest terms" according to Carpenter. Let me now attempt to state my theory in its "lowest terms." It is this:

(1) The Pterygota are descended from a common stock with the Thysanura *Ectotrophica;* their immediate ancestors were probably Lepismatoid in form.

(2) The common Lepismatoid stock mentioned above, together with all the Thysanura Ectotrophica, originated from some earlier form of Thysanura *Entotrophica.*

(3) The very ancient Protura and the even older Collembola are remnants which represent side-branches from an extremely ancient common ancestor shared by all types of entotrophic Apterygota.

(4) This common ancestor of all known insect types was, in its turn, derived from an extremely simple, terrestrial type of arthropod called by me the "Protaptera," and defined on pp. 83-84 essentially as *neither progoneate nor opisthogoneate,* but as having had, most probably, five pairs of gonads segmentally arranged; also without a definite tracheal system, and with only four segments to each walking-leg, and probably undivided cerci.

It will be seen that Carpenter stresses the wrong points throughout. Having brought into the discussion the Chilopods and Diplopods, he has altogether overlooked the much more important groups of Pauropods and Symphyla, with which my theory was much more intimately concerned, and then proceeds to develop the extraordinary argument that my theory is not new, but was anticipated by Tothill. Let us follow his argument further (p. 533):

"Tothill, for example, in his 'Ancestry of the Insects' (this Journal, 42, 373, 1916) concluded that the Pterygota originated from the Apterygota, and that the Apterygota 'arose from an ancient Chilopod stock.' Aside from mere wording, this is the same view as that of Tillyard . . ."

And he concludes his argument as follows:

"At any rate, if Tillyard's conception of the relationship between the hexapods and other existing arthropods is accepted, Tothill and his predecessors should be given due credit for already having expressed the same view."

Now let us confront Tothill's argument with Carpenter's, by actual quotation from the former's paper. I have searched that paper through and through for the statement given by Carpenter, viz. that the Apterygota "arose from an ancient Chilopod stock," and I cannot find it. What does actually occur, however, on p. 383 of Tothill's paper, is the following:

"If, as seems probable, the Pterygogenea [*not,* be it noted, the Apterygota or Apterygogenea, R. J. T.] arose from an ancient Chilopod stock, it may be interesting to speculate concerning the ancestry of the Chilopods."

Following this line of argument out, Tothill concludes as follows (p. 384):

"In conclusion a survey of the available data shows that the Pterygogenea are closely related to Chilopods and were quite possibly derived from an ancient stock in which the maxillipedes were not developed as jaws. Also that the Chilopods were in turn very likely, though by no means certainly, derived as Handlirsch suggests, from ancient generalized trilobites."

It should be carefully noted that, in this summary, Tothill does not even deign to mention the Apterygota. Let us enquire why this is. His reasons will be found on p. 376 of his paper, where he says, at the end of the first paragraph:

"Be this as it may, the various specializations found in the group [i. e. in the Apterygota, R. J. T.] seem to make it certain that *it is not in the direct line of descent of the great Pterygogenea complex.*" The italics are my own.

And again, on the same page, at the end of the second paragraph, after discussing *Stenodictya* and the origin of wings, Tothill remarks:

"This seems to indicate the method of origin of the wings and *does away with the necessity of deriving the winged insects from the Apterygogenea.*" The italics are again my own.

Tothill's theory, then, may be briefly summarized as follows:

(1) The Apterygota have nothing to do with the case.

(2) The Progoneata (p. 382) "throw little or no light upon the present discussion."

(3) The Pterygota (***not*** the Apterygota) are derived from "an ancient Chilopod stock," which is figured and defined (p. 378, fig. 3) as resembling a modern Chilopod without the poison-jaws.

(4) The Chilopods, in their turn, were very probably derived from "ancient generalised trilobites."

It will therefore be seen that Tothill, in a way, attempts to harmonize Brauer's original theory (but omitting the Apterygota) with Handlirsch's theory. Apart from this highly original idea, there is nothing new in his theory at all. Rightly or wrongly, therefore, I did not deal with Tothill specifically in my survey of existing theories.

I must leave my readers to decide how much resemblance there exists between Tothill's theory and my own. Personally I can see none. What I finally wish to point out is that Carpenter, in his analysis of the question, ***misquotes*** Tothill. Here is the case in a nutshell:

J. D. Tothill.	*F. M. Carpenter.*
p. 376—The Apterygota are "not in the direct line of descent of the great Pterygogenea complex."	p. 533—"Tothill . . . concluded that the Pterygota originated from the Apterygota."
p. 383—"If, as seems probable, the Pterygogenea arose from an ancient Chilopod stock."	p. 533—"[Tothill concluded that] the Apterygota 'arose from an ancient Chilopod stock'."

Carpenter, writing as a paleo-entomologist, deals with my new theory without a single reference to the part which I claim is played by the Collembola in it, or the Pauropoda, or the Symphyla, or the phenomena of protomorphism, anamorphism and epimorphism, or the possible common origin of progoneate and opisthogoneate types of reproductive systems! These matters are of the very essence of my new theory. . . .

R. J. TILLYARD.

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THE AUSTRALIAN LATE PALEOZOIC GLACIATIONS.

There has recently appeared in the *Bulletin* of the Geological Society of America a far-reaching and clarifying article by David and Süssmilch on "Upper Paleozoic glaciations of Australia" (1931). The writer greets this presentation with congratulations, since it has cleared away an important error made by him in his "Review of the Late Paleozoic formations and faunas," published by the same Society in 1928. Constructive discussions in regard to differences in interpretations are always in order, and as we do not yet agree on some very important Carboniferous and Permian correlations, further explanations are now offered in the hope that they will bring greater harmony.

The most valuable conclusion brought out by David and Süssmilch in their paper is that a glacial period occurred toward the close of the Lower Carboniferous in both eastern Australia (Kuttung series) and Argentina (Paganzo series). My Australian friends say that this glaciation took place at some time between the late Lower Carboniferous and the close of the Westphalian; but as I now see it, the glaciation occurred toward the close of the Mississippian. It was then followed by a long time of milder climates, the length of which was at least that of the Upper Carboniferous period (probably forty million years), after which came the Lochinvar cold time of the late Lower Permian. In any event, the Kuttung stratigraphy of New South Wales now confirms what the Argentinian geologists have long been seeing, namely, a glacial time preceding the one that is associated with the Glossopteris flora.

The Lochinvar glaciation appears to me to be the equivalent of the Talchir tillite of India and the Dwyka of South Africa. This widespread glaciation of the southern hemisphere I now place in the late Lower Permian instead of late in the Middle Permian as was done in 1928. This change is due to an investigation of the fusulinids in the lowest part of the Productus limestone of India (see page 547), the detail of which will be published elsewhere.

Finally, the younger glacial materials of Australia, if they are actually indicative of ice-ages in the later Permian, are apparently peculiar to that continent, and remain unsolved problems in the climatology of Permian times.

We will now proceed to a detailed discussion of our varying interpretations.

Early Lower Carboniferous or Burindi series.—I agree with my Australian colleagues that the Carboniferous of eastern Australia begins with the abundantly fossiliferous marine Burindi series. This correlation need not detain us long in the present discussion, since it has but little bearing on the ages of the five "glacial horizons" of the higher formations. Accordingly I need only repeat my conclusion of 1928 that the age of the Burindi series is about that of the lower Avonian of England, or the Burlington-Keokuk of the United States.

"In New South Wales, in the Hunter area," according to David and Süssmilch, "there is evidence of a strong break but of an epeirogenic rather than an orogenic character, at the top of the Burindi. . . . This may be termed the Wallarobba disturbance" (p. 518). This elevation in eastern Australia was followed by a long land interval (late Lower Carboniferous time), during some part or all of which the Kuttung series was deposited.

Late Lower Carboniferous or Kuttung series.—This great mass of highly variable non-marine deposits, essentially of volcanics and detritals, begins with the very thick Wallarobba conglomerate, tuffs, and andesitic flows, that together make up the Basal Stage between 1,500 and 4,000 feet thick. Then follows the Volcanic Stage (2,300-3,185 feet), which in the Currabubula district also has tillites and varved shales. The Kuttung series is closed by the Glacial Stage, having the Seaham glacial beds between 3,150 and 5,080 feet in thickness.

According to W. R. Browne (1927), most of the Kuttung conglomerates in the Gosforth district have a pink granite or aplite as a "constant constituent," and in places they include granodiorite masses up to 10 feet across. One of the conglomerates merges upward into a tillite with varved shales, suggesting formation on the floor and around the margin of a very large fresh-water lake, with ice-capped granite highlands some distance away to the south. In at least one place was seen a small patch of glaciated floor, with the scratches striking N. 15°W. (p. 265). In the Winder's Hill division, "seven horizons of varve-rock have been noted" (p. 230). At least two of the conglomerates "have been proved of aqueo-glacial origin by the occurrence in them of ice-scratched pebbles" (p. 231); they are "probably outwash gravels" (p. 265).

G. D. Osborne (1925) says that in the Clarencetown-Paterson district the upper Kuttung has three tillite and two fluvio-glacial beds, and two zones of varved shales, in a series of tuffs. In the Seaham area the glaciers at times overrode the sediments and produced the contorted varve-rocks (p. 79)

Because of the coarse nature of the sediments, the glacial detritus, and the vast amount of tuffs and volcanics, it is evident that the Kuttung series is of very rapid deposition and could readily have been accumulated during a very small part of late Lower Carboniferous time.

The series is characterized by the Rhacopteris flora, and particularly so in the upper part. "From every locality, also, glacial beds are found to be intimately inter-stratified with *Rhacopteris*-bearing beds" and this flora "ascends to within a few feet of the base of the overlying Lower Marine Series" (David and Süssmilch, p. 492).

In the opinion of the leading Australian paleobotanist, A. B. Walkom, "The Rhacopteris flora does occur abundantly in the lower part of the Glacial Stage of the Kuttung Series and there is no reason why the record of its occurrence in the upper part of the same Stage should not be correct. . . . . The Rhacopteris flora may have lingered into the Upper Carboniferous in this region. Between the Carboniferous (Burindi and Kuttung Series) and the succeeding Permian strata there is a very marked palaeontological break in Australia, none of the plants and practically none of the animals continuing upwards from the Carboniferous. No trace has yet been found of any Upper Carboniferous flora in Australia and there appears to be a distinct stratigraphical break representing perhaps the greater part of Upper Carboniferous time" (1929, p. 167).

The Rhacopteris flora does not appear to me to be one of an ice-age, rather is it one of low lands and at least temperate climate, into which the glaciers descended out of the highlands. That this flora, however, lived in a seasonal climate is indicated by its occurrence in varved clays, and besides, its floral affinities are those of the Kulm, as the authors state—a lowland flora of a moist and not a glacial climate.

It is now apparent that I was in error in 1928 in regarding the Seaham glacial beds down to the Paterson rhyolite as belonging in the Permian series. Now, with the clearer and more detailed résumé of the Kuttung stratigraphy before me, I gladly recant and accept the evidence of the Australian geologists. On the other hand, I still see no evidence that any part of the Kuttung is as late as "Middle Carboniferous" or Westphalian in age.

Permian.—What was formerly called Permo-Carboniferous and Bowen series is now termed the Kamilaroi system; it is a sequence with a maximum thickness of 17,000 feet. The change in terminology is welcome, since it is to be hoped that the hybrid term Permo-Carboniferous will soon drop out of sight.

The Greta Coal Measures, a persistent terrestrial deposit with workable coal seams in the midst of the marine Kamilaroi system, is taken as the central datum horizon for correlation of the various local sequences of the Australian Permian. In David and Süssmilch's Figure 3 the Greta is referred to the base of the Middle Permian.

My greatest point of difference with the David and Süssmilch Permian correlations lies in the "lower part of the Lower Marine Series," termed by them the "Lochinvar Marine Stage" (2,400 feet thick) with its basal "Lochinvar Glacial Beds" (300 feet). These boulder beds, as well as the overlying marine clays, are referred to the Upper Carboniferous (p. 485). On page 497 they say: "The ice-sheets responsible for this glacial deposit must have come down close to sea level in early Kamilaroi (probably late Upper Carboniferous) time, for [in a zone 3 feet thick] at the top of these glacial shales are found a few of the marine pelecypod *Eurydesma hobartense*. . . . . A nonsequence must certainly occur, both lithological and paleontological, at the base of these Lochinvar beds, but nevertheless, there is no angular unconformity, and apparently no evidence of contemporaneous erosion." The very fact, however, that the above-named guide fossil occurs in these glacial beds is proof sufficient to me that the strata having it are of Permian age, since nowhere (Australia, Africa, India) does the genus *Eurydesma* occur in Upper Carboniferous faunas; it is restricted to the earlier Permian.

That there was a land interval and a long time of erosion between the Kuttung and Lochinvar epochs is indicated by the statement that "The terrane, which had been supplying the boulders to the Kuttung, appears to have been now submerged, or at all events to have been no longer available as a source of supply of the material forming the erratics. In place of the dominant granites, aplites and quartz-porphyries of the Kuttung glacial beds, it is found that diorites, gabbros and porphyrites are more characteristic of the Lochinvar glacial beds. . . . . This remark also applies to the three younger glacial horizons" (pp. 497-498). In another place these authors say, "While no angular unconformity has as yet been observed at the top of the Kuttung Series, there is certainly a strong paleontological and lithological break with a considerable amount of transgression. This break may be termed the Lochinvar break" (p. 518); Süssmilch had earlier called it the "Hunterian disturbance" (1920, p. 282). According to Browne (1927), in the Gosforth district the Lochinvar shales usually begin with dark red strata, and in this contrast sharply with the Kuttung. That the Lochinvar marine series is a transgressive one is furthermore shown in that different basal members (either of the lower shales or the higher sandstones with plant débris) rest on the Kuttung continental deposits (p. 246).

The marine faunas of the Kamilaroi, and the Glossopteris flora as well, in my opinion are totally different from those of the Kuttung, and, what is more significant, the marine fossils of the Lochinvar stage are in harmony with the rest of the New South Wales Permian. This interfaunal identity throughout the whole of the Kamilaroi series is well known to Australian paleontologists and it was pointed out in my paper of 1928 (pp. 868-869). My friends see in a *Seminula* and a *Spirifer* Upper Carboniferous time relations, and ties with the Burindi series as well, but unless the species of these genera are carefully studied outside and inside (which has not been done), no dependence can be had on them for correlation, and furthermore, it is not often that these particular genera are valuable in chronogenesis. Moreover, I see no dependable widespread stratigraphic value in the corals *Monilopora,* *Trachypora, Favosites,* and *Cladochonus;* these fossils probably have local significance, but can not be relied on in determining period or even epoch values.

David and Süssmilch then go on to say that immediately above the Lochinvar marine stage is the Harpers Hill zone, and that "*Eurydesma cordatum* is specially characteristic of this horizon," forming a "regular 'oyster-bank' type of deposit, occurring in vast numbers in among the boulders of the conglomerate"; the boulders were "dumped by shore ice" and were overwhelmed by showers of volcanic tuff. Finally, this horizon "is considered to be the basal bed of the Permian . . . . and so dividing the Permian from the Upper Carboniferous" (p. 499).

The very fact that David and Süssmilch say, "We hold tentatively that there was a quiet passage from Upper Carboniferous into Lower Permian time about half-way up in this Lower Marine Series" (p. 483), shows that no break in sedimentation is evident here. In other words, there is no break from the Lochinvar series into the *Eurydesma cordatum* beds at the base of the Rutherford stage of the Lower Marine series. Accordingly we are asked to accept this zone as the dividing line between two systems in a continuous marine series.

We must now ask: Have guide fossils any more value in correlation when they occur in abundance than when they are less common or even rare? Ever since Waagen's day *Eurydesma* has been regarded as a cool-water bivalve, and in the *E. cordatum* beds it occurs among the boulders of a conglomerate, "a minor glacial horizon. The tumultuous bedding of the boulders, many of them with their principal axes at right angles to the planes of bedding, and the faint striations, suggests the action of ice floes rather than of glacier ice" (p. 499). We have seen above that *E. hobartense* also occurs in a glacial bed (Lochinvar), and therefore we ask: If *E. cordatum* is Permian in age, why not *E. hobartense,* when all the intermediate fossils are also of the same Kamilaroi fauna? It seems as if my friends in these and in the other cases mentioned by them are stressing the far rarer Carboniferous indications and overlooking the more common and significant ones heralding Permian time.

Regarding *Paralegoceras jacksoni* and its supposed "Upper Carboniferous" age (pp. 510-511), I can form no opinion until I see good specimens. The published illustrations are inadequate to show all the characters and therefore the degree of evolution.

In summation, David and Süssmilch say: "It would be premature to attempt to make a final classification of a group of rocks [Kamilaroi] containing such an intricate admixture of Carboniferous and Permian types" (p. 517). More detailed field work is always in order, but it seems to me that the stratigraphic correlations of Australia are shrouded in the "lumping" paleontology of two generations ago. What is needed is for a paleontologist to assemble all the Kamilaroi collections and work them out according to modern standards, when the "intricate admixtures" will vanish and the hoped for harmony be at hand. We need a stratigraphic standard for the Carboniferous and Permian systems of the eastern Australasian region to compare with that of the Tethyian region that also embraces Western Australia.

The Glossopteris flora in Peninsular India makes its appearance immediately above the Talchir tillite, and in the Salt Range of northwestern India in the Lower Productus limestone about 530 feet above the equivalent of the same glacials (= 384 feet of Speckled sandstone and 145 feet of Lower Productus limestone). In South Africa, *Gangamopteris cyclopteroides* occurs at the very base of the Dwyka tillite, and in Australia this genus first appears about 2,000 feet above the base of the Lower Marine series. In all these continents the Glossopteris flora then continues to appear oftener in higher beds and, becoming more differentiated, attains its maximum in the early part of Upper Permian time.

Walkom (1929) says: "The Glossopteris Flora in New South Wales is separated from the earlier flora of the Kuttung Series by an absolute break, not one of the species known from the Kuttung Series occurring in association with the Glossopteris Flora. . . . . Near the very base of this Series there is a thickness of one hundred feet of sandstone containing plant remains, but those fragments which have been obtained have all proved to be undeterminable. It is, therefore, impossible to say definitely whether the plants on this horizon show affinities with the earlier Kuttung flora or with the Glossopteris Flora. The recent discovery of *Eurydesma hobartense* below this horizon, however, seems to support, as a reasonable conclusion, the suggestion that the flora of this sandstone will prove to have affinity with the Glossopteris Flora" (p. 163).

Conclusions.—David and Süssmilch are so liberal as to say: "W. S. Dun, paleontologist to the Geological Survey of New South Wales, inclines to the view that the Permian marine fauna can be carried down probably to the base of the Lochinvar glacial shales. He bases his opinion on the character of the brachiopods, a group which he has long studied, so that no little weight should be attached to his views. He also stresses the point that *Eurydesma hobartense* occurs at Lochinvar immediately above the glacial beds in strata perfectly conformable with them" (p. 516). A. Gibb Maitland is likewise of the opinion that the brachiopods of Western Australia show direct relationship with those of the Salt Range, and in both regions these fossils are of undoubted Permian deposits (p. 517).

On the other hand, Professor Seward finds it "difficult to believe that events which occurred during the latter half of the Upper Carboniferous period are entirely lacking in the geological records not only of Australia, but of India and South Africa" (p. 576).

And yet this is the way the organic sequence in those continents appears to me. To say that the Glossopteris flora in the southern hemisphere holds the time of the Upper Coal Measures in the northern one, is to refuse to face the abundant evidence of the marine faunas of the Upper Carboniferous and Permian of the world. It is difficult, I grant, to believe in this Upper Carboniferous absence, if one holds that geologic records must everywhere be fairly alike, but when one knows through field experience that the sequences are everywhere broken and often greatly so, it is not at all difficult to follow their actual teachings.

Glacial times.—David and Süssmilch state that in a thickness of strata, inclusive of volcanic rocks, of over 11,000 feet, or, if maximum thickness be taken, of 15,000 feet, there are no fewer than five "glacial horizons." Accordingly, "Glaciation of Australia was not confined to a limited period of geological time, such as the Middle Permian, as claimed by Schuchert, but had its beginnings in the Kuttung epoch (Kulm) and continued on until the top of the Lower Permian epoch when it finally disappeared" (p. 520). To the first conclusion I now agree; but the second one can not be accepted.

Regarding the "first and second glacials" of the Lower Carboniferous Kuttung series, it is not apparent how they can continue unbroken into that of Lochinvar time of the Permian ("third glacial"), not even on the evidence of David and Süssmilch; in fact, they themselves point out a break between the second and third glacials. It is my view that the Kuttung glaciation is separated from the Lochinvar one by the whole of Upper Carboniferous time, which endured several tens of millions of years, and that a similar interval occurs in the glacials of Argentina.

The third or Lochinvar glaciation was in Permian time—a new one that took place long after the others and belongs to the widespread ice-age of the southern hemisphere. In several places David and Süssmilch regard this glaciation as the main one in Australia, correlating it with the tillites of Tasmania, Bacchus Marsh of Victoria, and South Australia. So far, evidence of only one prolonged and intensive glaciation has been met with, namely, that of the Lochinvar glacial beds (p. 506). This is also my view, and, as stated earlier, I correlate the Lochinvar with the Talchir and the Dwyka.

However, the Lochinvar glaciation and its correlates in Australia, and the Dwyka and Talchir tillites of other continents, are surely not of Upper Carboniferous time, nor even of the early Permian, but on the basis of local and international correlations must be younger than the Schwagerina zone of the Lower Permian.

In this connection, I may digress to say that I have recently restudied the Salt Range sequence, especially the fusulinid-bearing members of the Lower Productus limestone, which rests upon the

Talchir tillite. Director Hobson of the Geological Survey of India was so kind as to send to Yale for study by Dunbar a great abundance of fusulinid material, which all turns out to be of one species, *Parafusulina kattaensis*. The genus *Parafusulina* is common in the top of the Lower Permian and throughout the Middle Permian of West Texas, where it succeeds the zone of *Schwagerina* and *Pseudofusulina*, which occur in the older part of the Lower Permian.[1] *Schwagerina* has never been found in the Productus limestone series of India and since it is widely spread in Russia and China and even in the Himalayan region its absence from the Fusulina limestones of the Salt Range would seem to be strong evidence that its horizon is not there represented. We may infer, therefore, that the abundance of *Parafusulina* and the absence of the older genera just above the Talchir tillite indicate an age for the basal Productus limestone series in the upper part of the Lower Permian or somewhere in the Middle Permian.

The fourth and fifth glacials of Australia appear to be of local interest only. The fourth is separated from the third or Lochinvar glacial by 2,400 feet of strata; from the fifth by (1) from 1,500 to 2,000 feet of the Farley and Rutherford stages, (2) 200 feet of Greta Coal Measures, and 2,000 feet of locally interbedded volcanics, and (3) about 1,000 to 2,500 feet of the Branxton stage. The fifth glacial consists of two divisions: A, below, which is at the top of the Branxton stage, and B, which is in the 400 feet of the Muree stage. David (1923) says that the erratics of the Muree beds are "more or less rounded by the action of the sea waves," but that some still show glacial striae. Coleman, he says, regards these occurrences "as a marine boulder clay," and such occur throughout a thickness of 300-500 feet lower. Some of these erratics have sizes up to 5 feet, and were dropped by "floating ice rafts" (p. 17). These beds with glaciated boulders are so common in places in the Bolwarra conglomerate as to give the appearance of "a marine boulder clay." These erratics came from the southwest of West Maitland (David and Süssmilch 1931, p. 500).

Coleman in his "Ice Ages" (1926) says: "At Branxton there appeared to me to be thin beds of true tillite interstratified with the marine deposits, though the Australian geologists do not interpret any of the beds as due to land ice" (p. 146).

From the position of the fourth and fifth glacial stages we see that these ice-ages, if such they be, occurred long after the main or Lochinvar glaciation, in fact so long afterward that they can not be regarded as recurrences of cold times spaced in chronogenesis as were those of Pleistocene time.

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[1] Dunbar, C. O., and Skinner, J., New fusulinid genera from the Permian of West Texas, this Journal, 22, 252-268, 1931.

The question therefore arises: Are the fourth and fifth glacials actually of recurrent cold times, with the land covered by continental glaciers that attained the sea? Certainly no marked change appears in the marine faunas. Can these glacials be of ice transportation, from ice formed in the winter along a shore that had *morainic deposits made in Lochinvar or even in Kuttung times,* and dropped in a sea with moderate temperatures? If so, we then can say that Australia had two late Paleozoic glaciations—late Lower Carboniferous and early Middle or late Lower Permian—and that the other glacial horizons include merely transported shore-ice materials of the Lochinvar moraines. The writer hesitates to ask, Can these fourth and fifth glacials be in overthrust masses?

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POSTSCRIPT.—Since this paper was sent to the editor, Dr. A. K. Miller of the University of Iowa has restudied *Paralegoceras jacksoni* and finds it to belong to the genus *Metalegoceras,* known only in Permian formations. His results will be published in a forthcoming number of the Journal.

C. S.

SCIENTIFIC INTELLIGENCE.

CHEMISTRY AND PHYSICS.

Monograph on Biochemistry. "The Glycosides"; by E. F. ARMSTRONG, and K. F. ARMSTRONG. Pp. vii, 123. London, New York and Toronto, 1931 (Longmans, Green and Co., $4.25).—This is a monograph devoted entirely to the glycosides, and originally comprised a section of a former work on carbohydrates. Important developments within the last ten years have greatly increased our knowledge of sugars, and new and clearer views regarding the structure of these substances have been developed. Progress in the glycoside field has been made in many directions. The subject matter is, however, still very complex and a general treatise like this one is of the greatest assistance to any worker in biochemistry. The workers in Plant Chemistry are in great need of a book of this character. Workers in horticulture, in agriculture are contributing to a better understanding of life processes and in an age of organic synthesis in our expanding industry it is very important to have an understanding of nature's processes and technique. The book will serve as a catalyst to the biochemical worker, and the subject matter constitutes a most important part of our growing biochemical literature. An important feature of the book is a very complete bibliography. This feature alone gives the book a value which enhances greatly its usefulness.

T. B. JOHNSON.

An Introduction to Organic Chemistry; by JOHN READ. Pp. viii, 365; 52 figs. London, 1931 (G. Bell & Sons, Ltd., 6/6).—This book would be a satisfactory text for a short course in Organic Chemistry. It gives a comprehensive outline of the subject, including in the first part of the book chapters on the purification, analysis, and determination of molecular weight of organic compounds.

Other desirable features are: (1) The inclusion of directions for seventy-eight experiments, each one being put in its appropriate place in the text; (2) The problems which appear at the end of each chapter, the answers to a great many of which are to be found in the back of the book; (3) The clear explanations of points of theoretical importance—optical isomerism, for instance.

On the other hand, the treatment of certain topics is weak. The important features of nomenclature are rarely mentioned, and the treatment of carbohydrates and proteins is so inadequate that the writer feels that the text would not be suitable for pre-medical students. The treatment of carbohydrates is too general in nature, no mention being made of the lactone structure of the sugars or any explanation given for mutarotation.

On the whole, the book can be recommended as a text of Organic Chemistry for students who do not intend going on with chemistry or medicine. It is well organized and written, easily understandable, and brings out many points of general interest.

ROBERT D. COGHILL.

Sensitive Flames:—Since the accidental discovery of the phenomenon of sensitive flames by LeConte in 1858 it has been the subject of a large number of experiments, but a detailed explanation of the phenomenon has never been given. Tyndall reached the conclusion that the effect of sound on jets of gas was to produce a condition of turbulence similar to that caused by increasing the pressure. Barrett was of the opinion that flames flare with the slightest increase in velocity and ascribed the effect of sound to a throwing of the tube, through which the gas flows, into vibration. As he viewed it, the flow of gas is thereby driven from the sides and urged more toward the center of the tube, and the current, thus being confined within narrower limits, must issue from the tube with increased velocity.

The nature of the instability of gaseous jets has recently been the subject of an extensive examination by G. B. BROWN in an attempt to discover the causes underlying their sensitivity to sound vibrations. The source of sound was a valve oscillator, in conjunction with an amplifier and a moving coil loud speaker, A great variety of flame jets were experimented upon, and the instability of smoke jets examined, both stroboscopically, and photographically.

Barrett's hypothesis was disposed of by shielding first the tubing and then the flame. In the first case no difference was found; in the second, the sensitivity almost entirely disappears.

If the orifice is below about ½ mm. in diameter the flame is short and the amount of ducking very small. If the diameter of the jet exceeds about ½ cm. the stream reaches to a great height but is very susceptible to drafts and suffers from periodic bulbous disturbances which travel upwards and help mask the effects produced by sound.

Between these limits all streams show a sensitivity to sound which is most marked when the stream is on the point of flaring. When any roughness or obstruction in the jet causes premature flaring, i.e. turbulence at a lower velocity, the sensitivity of the stream is markedly impaired and the range of frequencies to which it responds is lowered.

The position and construction of the tube supplying the gas affects the sensitivity, in so far as it can alter the way in which the gas streams out of the orifice. If the jet contains a plug of cotton wool the position and nature of the supply pipe has no effect upon the behavior of the stream issuing from it.

As regards the frequencies which were most effective, it was invariably found that for a given gas the frequencies producing the maximum disturbance were definite, and did not vary with the kind of jet used: they were constants for any particular gas.

The range of frequency to which gaseous streams are sensitive varies with the gas used, and with the size and character of the jet employed. With air the range is low, 80-900; with unlit gas somewhat higher and with ignited coal gas or hydrogen the range extends (with different jets) from 500 to over 18000.

The size and nature of the jet affect the range by altering the velocity which leads to turbulence. The jets with high frequency ranges, are those where the velocity for sensitiveness is high, and the ones with low frequency sensitivity, are those with low velocity.

The actual effect of the sound waves on a gaseous column is to cause regular undulations to proceed from the jet up the column, the upper part of the column breaking into turbulence. The wave length of these undulations depends upon the velocity of the stream and the frequency of the sound.

Although the condition of being on the point of breaking into turbulent motion is a criterion of sensitiveness to sound for all jets, and must therefore favor the production of sinuosities in the stream, nevertheless the turbulence produced by excessive velocity does not exhibit any sinuosity or periodicity of any kind. The sound does not, as is generally assumed, precipitate the state of turbulence into which the stream is about to fall—it produces a state of periodic disturbance which is quite distinct. *Phil. Mag.* 13, 161, 1932. F. E. B.

The Queen of the Sciences; by E. T. Bell. Pp. 138. Baltimore, 1931 (The Williams and Wilkins Company, $1.00).—Mathematics used to be defined as the science which treats of quantity, or magnitude, and their measurement. Here are some of the modern definitions. "Mathematics is a game played according to certain simple rules with meaningless marks on paper." (Hilbert). "Mathematics may be defined as the subject in which we never know what we are talking about nor whether what we are saying is true." (Russell). To such attenuation has the modern critical school brought the condition, of what this author calls, the Queen of the Sciences.

In this book he has given a comprehensive view of what mathematics is all about, its philosophy, its aims, and its methods. He tells in an entertaining way about invariants, groups, matrices, functions, transformations, and sets, and has a good deal to say about the present day morass of doubt concerning the meanings of the fundamental concepts of mathematics.

It is a book that will repay reading, if for no other reason, as a revelation of the tremendous sweep of thought which has been attained in this science. F. E. B.

The Theory of Spherical and Ellipsoidal Harmonics; by E. W. HOBSON. Pp. xi, 500. Cambridge, 1931 (Cambridge University Press and the Macmillan Company, New York, $11.50).—The main object of the present work is to find the form of the functions which satisfy Laplace's equation,

$$\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2} = 0,$$

and also the boundary conditions, especially over spherical or ellipsoidal surfaces, and to investigate the properties of the functions so obtained. In the first four chapters an account is given of the properties of the ordinary spherical harmonics, and an attempt has been made to make some of these investigations more rigorous than they were in the forms in which they were originally given.

In Chapter V the general definitions of the Legendre's associated functions are given, and a general account is added of the representation of the functions by integrals and series. Chapter VI contains investigations of the approximate values of zonal and associated functions. In Chapter VII the author takes up the general theory of the summability of the Legendre and Laplacian series, deriving results similar to those of the well-known Fourier series. Chapter VIII is devoted to the investigation of the addition theorems for Legendre's functions of the first and second kind. Chapter IX contains an account of the zeros of the associated functions of the first kind, and a less complete account for the case of functions of the second kind. Chapter X treats of harmonics for spaces bounded by surfaces of revolution and Chapter XI of ellipsoidal harmonics.

It is a book which will be highly prized by mathematical physicists. F. E. B.

The Theory of Groups and Quantum Mechanics; by HERMANN WEYL. Pp. xxii, 422; 3 figs. New York, 1932 (E. P. Dutton & Co., $6.00).—This work is a translation from the German second edition of *Gruppentheorie* und *Quantenmechanik*, by H. P. Robertson. In the past the most important application to natural science of the group concept was to the description of symmetry in crystals, but it has recently been recognized that the group theory is of fundamental importance for quantum physics: it here reveals the essential features which are not contingent upon a special form of dynamical laws or on special assumptions concerning the forces involved. All quantum numbers with the exception of the so-called principal quantum numbers are indices characterizing representations of groups.

The book contains five chapters in which are set forth the connection between groups and quanta. The first chapter discusses unitary geometry. The second is devoted to preparation on the physical side, but only so much has been given as appeared to the author to be indispensable for an understanding of the meaning and methods of the quantum theory. Chapter three develops the elementary portions of the theory of representations of groups, and chapter four applies them to quantum physics.

While mathematics and physics alternate in the first four chapters, in the last chapter the two are fused together showing how completely the mathematical theory is adapted to the requirements of quantum physics. In this chapter there are also further developments of the mathematical theory with particular reference to the theory of linear algebras.

It is a book solely of interest to the mathematical physicist.

F. E. B.

Lehrbuch der Mikrophotographie und Mikroprojection; by Kurt Laubenheimer. 2d Edition. Pp. xiii, 272; 187 figs. and 8 plates. Berlin, 1931 (Urban und Schwarzenberg, RM. 18; bound 20.40 RM.).—The technique of microphotography has made rapid advances in the last few years. It is the aim of this book to describe in detail the newest designs of apparatus, and the procedure involved in this domain. A considerable section of the book is devoted to the microscope. The construction of objectives is explained and the path of the red and the blue rays traced by colored lines. Other sections take up the camera, the installation for lighting, various arrangements for taking the pictures, the treatment of the negative and positive prints, microphotography in natural colors, and microprojection.

The whole subject is presented with such a wealth of detail that the book should greatly appeal to medical men, biologists, botanists, and mineralogists. F. E. B.

Cours de Physique; by Ch. Fabry. *Tome I*: Quarto. Pp. vi, 663; 339 figs. Paris, 1932 (Gauthier-Villars et Cie, 150 fr.).—This volume conforms to the course of instruction given at the Ecole Polytechnique to those who enter with a good mathematical foundation but who have only elementary notions of physics. They cannot be given an encyclopedic course and hence some choice of subject must be made and this selection is chosen rather on the basis of their future occupations. They will for the most part become engineers, technicians rather than pure scientists. For this reason the emphasis is laid on a knowledge of the phenomena and the laws which govern them and so the essential place is given to the most solid parts of physics, to those which make the most direct contact with the realities, even at the expense of the most interesting and highly philosophical of the modern theories.

The book is divided into three parts; the first entitled thermodynamics, consisting of fifteen chapters and running to some 300 pages, gives a fairly full and mathematical treatment of the phenomena of heat. The second part covering 60 pages is devoted to vibratory movements and their application to phenomena of sound. The third part of 350 pages takes up electricity, beginning with electric currents, and treating chiefly those phenomena which have application to engineering.

The book is well and clearly written and may be recommended for collateral reading to second year students. F. E. B.

Kepler-Festschrift; by KARL STÖCKL. Pp. 355; 18 pls., 37 figs. Regensburg, 1930 (Druck der Graphischen Kunstanstalt Heinrich Schiele, 15 RM., bound 18 RM.).—The contents of this volume fall naturally into three parts. The first describes the memorial festival held in Regensburg in September 1930, in which a great number of representatives from all Germany took part. The second treats of Kepler's life in, and his relation to Regensburg, with particulars as to the Regensburg memorial. The third part contains seventeen essays and addresses by different professors on the different aspects of the life and work of Kepler.

The Germans see in Kepler, and perhaps justly, one of the greatest geniuses of all time. The discovery of the form of the orbits of the planets was a deed which assured him ever a place as the prince of astronomers, but he achieved other great results and his advance beyond Copernicus was even greater and more eventful, than Copernicus' advance upon Ptolemy.

In the mechanical comprehension of planetary motion it was a gigantic forward step, his placing the center of the system of the planets in the sun itself, while the best that Copernicus could do was to assign the middle point of the system to the central point of the earth's orbit.

His studies on the magnetism of the earth had raised in his mind the question, "why do the planets move and what forces compel them to revolve about the sun?" and he was led to consider whether the sun and the planets might not be great magnets between which attractive forces act. He developed the assumption of a general attraction between the heavenly bodies and concluded that the earth seemed to obey such an attraction. This has its seat in the sun which is not only the source of light but also the source of motion. This book asserts that Kepler showed that these forces diminished with the distance and pointed to the probability that they fell off with its square. He also showed that the bodies attracted each other proportionately to their masses.

Von Humboldt declared that Newton was not exclusively the author of the law of universal gravitation but that it should be known as the Kepler-Newton Law.

The book contains a well-digested account of Kepler's activities and researches. F. E. B.

GEOLOGY.

Petroleum in the United States and Possessions: A Presentation and Interpretation of the salient Data of Geology, Technology, and Economics in each State and Possession treated according to the conventional Major Field Divisions; by RALPH ARNOLD and W. J. KEMNITZER. Pp. xxi, 1052; 2 maps, 37 figs.; 91 tables. New York and London, 1931 (Harper and Brothers, $12.50).—A vast mass of information has been assembled and skilfully presented in this impressive volume. The book begins with a summary of the petroleum situation in the United States as a whole, giving a synoptic view of the geology of the occurrence of the oil, the history of the industry, technologic features, and economics. The major oil fields are then taken up consecutively, beginning with the Appalachian field. The facts concerning each major field division are outlined, followed by a more detailed analysis according to States.

The treatment by States follows the general scheme of giving a historical review, a condensed account of the geology of the oil and gas fields, classification of the area of the State into proved and prospective oil and gas land, a technological and statistical review, a review of the economics, including the amount of money invested and the return on the investment, and lastly, an appraisal of the future possibilities. All is clearly and smoothly presented, without technical or scientific jargon, and anyone interested in either the geology or the economics of the oil industry can turn with profit to these enlightening pages.

A stupendous amount of statistical information has been compacted into this volume. Among it we find unexpectedly bits of information that transcend in importance their usefulness to the geology of oil and gas. Of the total area of the United States 20.2 per cent consists of igneous and metamorphic rocks and 79.8 per cent of sedimentary rocks.

Thirty-five per cent of the area of the United States comprises the proved and prospective oil and gas land. Up to January 1, 1929, 1.25 per cent had proved productive; 0.67 per cent, or 7,037 square miles, had proved productive of oil, and 0.58 per cent, or 6,156 square miles, productive of gas only.

Commercial production began in 1859, when 2,000 barrels of oil were produced; in 1929 the output had reached one billion barrels. During that time 61.6 per cent of the output came from Paleozoic strata, 5.8 per cent from Mesozoic, and 32.6 per cent from Cenozoic.

The total number of wells drilled to the end of 1928 was 777,882. Of these 50,398 are regarded as wildcat wells. "The average wildcatter has had about 1 chance in 24 of opening up a new oil field." The total return from the sale of crude oil, natural gas, and natural-gas gasoline from 1859 to 1928 inclusive, has been $19,287,586,000.

The ultimate quantity of oil available on January 1, 1930, is said to be 27,003,474,000 barrels, or 70.6 per cent of the original amount of recoverable oil. How this estimate was reached is not disclosed, probably owing to limitations of space, but the sad fate of the many previous estimates of the amount of recoverable oil still underground in the United States warns us not to take this seemingly precise figure too seriously. It shows clearly, however, that in the opinion of the authors the date of exhaustion of our oil resources is farther distant than was thought probable a few years ago. ADOLPH KNOPF.

Catalogue of the Marine Pliocene and Pleistocene Mollusca of California and Adjacent Regions; by U. S. GRANT, IV, and HOYT RODNEY GALE. Mem. San Diego Soc. Nat. Hist., Vol. I. Pp. 1036; 36 plates, 15 figs., 4 diagrams, 3 tables. San Diego, 1931 ($8.00).—This truly monumental volume begins with a summary of the stratigraphy of the Pliocene and Pleistocene formations of California and an epitome of the geologic history of the region during these epochs; it continues with a systematic treatment of the molluscan faunas.

Two features of the first part have exceptional interest.

(1) In the Pleistocene formations, there are alternating cold and warm water faunas which can be correlated with the migrations due to glacial and interglacial epochs. Four cold-water faunas are identified with the four glacial epochs which Blackwelder has recognized in the Sierra Nevada. These faunal migrations, resulting from widespread climatic fluctuations, are considered the most valuable aids in correlation of the Pleistocene formations, not only from basin to basin in America, but from here to the standard section of Europe.

(2) The authors believe that California experienced only local warping during Miocene and Pliocene time and that the orogeny which folded and faulted the Tertiary formations of the Coast Ranges followed the first glacial epoch of the Pleistocene.

The second and larger part of the work has entailed a critical and exhaustive study of the hundreds of molluscan species which occur in these beds. Wherever possible the authors have located and restudied the types of the older species. The majority of the species here found fossil are still living in some part of the Pacific. The recent as well as the older faunas have therefore been studied and the distribution of each species in space as well as in time is recorded in so far as possible. The grouping of species into sections, subgenera, genera and higher taxonomic units has been considered, and several large and important families have been given extensive revision. Full bibliographic synonymies are followed by notes on the specific characters, the distribution, the source of the types and, where possible, the present location of the type specimens.

The careful organization of the material, from the table of contents and finding lists at the front to the excellent plates at the end, will make this great work a boon and indispensable aid to all future students of Tertiary mollusca. C. O. D.

Brachiopods of the Upper and Middle Devonian of the Turkestan; by D. NALIVKIN. Pp. 221; 10 plates. Mem. du Comité Geol., n. s., Livraison 180. Moscow, 1930.—This important monograph in Russian, with a forty-four page English summary, reviews the stratigraphy of the thick Devonian sediments of Turkestan, and describes the brachiopods, which constitute the predominant element in the faunas.

In this part of the old Tethian geosyncline, Devonian rocks have a very great but unmeasured thickness. Due to the present complicated structure, the stratigraphic sequence is based entirely upon paleontology. Two distinct facies are displayed; the first of black shales and thin-bedded limestone, with limited faunas confined to occasional zones; the second of massive, commonly reef-like limestones, filled with "banks" of brachiopods. Successive zones characterized by *Calceola, Stringocephalus* and *Hypothyridina* show the presence of far-flung faunal zones of Middle and early Upper Devonian age. Certain beds, filled with large pentamerids, are here transferred from the Silurian to the Middle Devonian.

Among the fossil brachiopods described, we may note the new genus *Monticola,* tentatively referred to the *Rhynchonellidae; Carinatina,* a remarkable subgenus of *Atrypa; Cyrtospirifer,* a subgenus of *Spirifer;* and *Eoreticularia,* a subgenus of *Reticularia.* C. O. D.

Papers from the Geological Department, Glasgow University, Vol. XIV (quarto reprints for 1927-1931), 1931.—This volume includes 5 reprints from the Transactions of the Royal Society of Edinburgh.

The first paper, by Dr. Ethel D. Currie, describes a collection of echinoids from the Jurassic and Eocene rocks of Somaliland. It presents a new genus *Farquharsonia.* The corals of the Somaliland collection are described in a second paper by Prof. J. W. Gregory. A few of the corals are of Jurassic age but most of them are Eocene or Oligocene. A new Eocene genus, *Tubicora,* is defined.

Papers three and four treat of the geology of Kintyre, southwest Scotland. Mr. William J. McCallien describes the stratigraphy and structure of the very complex metamorphic series and shares with Mr. R. B. Anderson the description of the Carboniferous stratigraphy.

The fifth paper by Dr. John Weir is a monographic treatment of the bellerophontid gastropods of the Carboniferous of Great Britain and Belgium. C. O. D.

The Grand Coulee; by J. HARLEN BRETZ. Pp. x, 86, with 41 figs., colored map, and 8 stereoscopic views in pocket. New York, 1932 (American Geographical Society, Special Publication No. 15; $4.00).—The most remarkable single unit among the scabland tracts of central Washington, treated by the author in numerous earlier publications,[1] is the Grand Coulee, a canyon 50 miles long, one mile wide, and nearly 1,000 feet deep. Its now streamless course cuts deeply into the basalt of the Columbia Pleateau, and its floor is marked by gigantic potholes, dry cataracts, and bars of gravel 200 feet thick.

The origin of this extraordinary feature is bound up with the origin of the entire plexus of scabland tracts that channel the Columbia Plateau. The author contends that the drainage of the Columbia River was dammed by ice sheets at least twice, and that each time the escaping water was forced to flow across the pleteau surface in enormous volume, with resulting excavation of the canyon. As the reader who is not familiar with the author's interpretation of scabland genesis will probably fail to get from this book a clear picture of the cause and initiation of cutting of the Grand Coulee, he would do well to consult the paper referred to in the footnote. With this background he can proceed with the author to consider the exact mode of channel excavation. The conclusion is reached that the northern half of the coulee trench was made by the recession of falls under the influence of a gigantic volume of proglacial water. This leads to an interesting discussion of the erosional features of falls in general.

The last ice sheet invaded the northern end of the coulee after it had been cut to its full depth. Wastage of the ice was accompanied by renewed overflow, which, however, was small by comparison with the earlier flood.

The story is written in the author's usual trenchant style, and is profusely and amazingly illustrated with diagrams and with photographs, many of which are aerial views, and a colored geologic map of the Coulee district adequately supplements both text and illustrations. A novel feature is a pocket containing eight stereoscopic aerial views, which portray in a remarkable way the relief features of the Coulee. R. F. F.

MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

Ursprung der Menschheit: Uber den engeren Anschluss des Menschengeschlechts an die Menschenaffen; by HANS WEINERT. Pp. xii, 380; 122 figs. (Ferdinand Enke Verlag, Stuttgart, 1932. (Ferdinand Enke, 21 RM., 23 RM. bound).—The first human family tree was that plotted by Ernst Haeckel in 1866, Weinert's book is dedicated to the memory of Haeckel. In fact, he endeavors to begin where Haeckel (in his Anthropogenie) left off.

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[1] The most comprehensive of these is The Channeled Scabland of Eastern Washington. Geogr. Review, **18**, 446-477, 1928.

In comparing the Old World apes with those of the New World Weinert concludes we have no right to assume that the human race had its origin in the New World. In other words, Man in his ascent did not pass by way of the Platyrrhine ape. The history of his ascent is traced rather through certain families of the Old World (Catarrhine) apes, especially the anthropoids. In this connection he places stress on certain fossil forms.

Under the gibbon: *Pliohylobates, Pliopithecus, Parapithecus,* and *Propliopithecus.*

Under the orang-utan: certain species of *Dryopithecus* and *Simia fossilis.*

Under the gorilla: *Paleopithecus, Sivapithecus, Dryopithecus fontani,* etc.

Under the chimpanzee: *Dryopithecus germanicus, D. Darwini, Australopithecus africanus.*

Under man: *Eoanthropus, Pithecanthropus, Sinanthropus, Homo heidelbergensis, H. neandertalensis, H. sapiens fossilis.*

The author draws a rather sharp distinction between the gibbon and the other three great apes—orang-utan, gorilla, and chimpanzee. He also stresses the differences between the orang-utan (orang = man, utan = wood) and the two African great apes—gorilla and chimpanzee. It is pointed out that orang-utan and gibbon have no frontal sinus, while gorilla, chimpanzee and man have a frontal sinus. The conclusion is that the human stem remained one with that of gorilla and chimpanzee, after the orang-utan (also the gibbon) stem had branched off.

In many ways the gorilla and chimpanzee stand nearer to man than they do to the orang-utan. For this reason Weinert coins a new term "*summoprimates*" to include the gorilla-chimpanzee-man group in contradistinction to the rest of the primates. In this summoprimate group, he would also place such fossil forms as: *Australopithecus,* certain species of *Dryopithecus, Eoanthropus, Pithecanthropus, Sinanthropus, Homo heidelbergensis, Homo neandertalensis,* and *Homo sapiens fossilis.*

A chapter is devoted to an intensive and comparative study of the gorilla-chimpanzee-man group, the conclusion being that the kinship of chimpanzee to man is closer than that of gorilla to man—"*dasz es einstmals einen Stamm gab, aus dessen Erbmasse bis zum heutigen Tage noch Schimpanzee und Mensch übriggeblieben sind.*"

Special emphasis is placed upon three fossil forms: *Australopithecus africanus, Pithecanthropus erectus* and *Eoanthropus dawsoni.* All three show a closer kinship to the living chimpanzee than to the gorilla. *Sinanthropus pekinensis* fits in between

Pithecanthropus and the primitive fossil race of Neandertal. For the author, *Eoanthropus* of Piltdown is still a problem.

Both the fossil and recent races of *Homo sapiens* are given ample treatment. The last of the 122 well-chosen illustrations is Weinert's idea of what the primate family tree looks like. Fourteen pages of bibliography and an index, happily not subdivided, complete a very satisfactory volume on man's physical evolution.

GEORGE GRANT MAC CURDY.

The Coming of Man; by G. G. MacCurdy. Pp. vi, 157, frontispiece and 58 text figures. New York, 1932 (The University Society, 468 Fourth Ave.).—Doctor MacCurdy has performed a difficult task in a thoroughly laudable manner. In this small volume he has concentrated the facts so far known about pre-man and prehistoric man, with the result that it is fascinating reading and, with its numerous illustrations and tables, is a valuable compendium for all who are interested in the prehistory of the human race.

The author briefly summarizes first the various periods of life on the earth and man's position in this scheme, both fossil and living, with man's ascent. Next the discoveries of fossil man are discussed, from the Java Man to the Cro-Magnons inclusive, the latter differing but slightly from the succeeding Mesolithic and Neolithic races, which in turn closely resemble modern man.

Next the cultural stages are examined—the earliest first, and then successively the Paleolithic, Mesolithic, Neolithic, Bronze, and Iron ages. After this Doctor MacCurdy reviews the cultural elements and their growth, such as food getting, habitations, fortifications, clothing, ornament, toilet, taming of fire, art, religion, language, music, writing, labor, industry, domestication of animals and plants, transportation, commerce, the healing art, textiles, pottery, and metallurgy, the last paving the way for the Modern Era.

More than two pages of glossary clarify the terms used in the text. A carefully compiled index of somewhat over eight pages completes this condensed volume on the prehistory of man which, like the other books in the series, should prove of much value not only to the specialist but to the ordinary, intelligent reader.

M. R. THORPE.

The Coming and Evolution of Life; by H. E. Crampton. Pp. iv, 103; frontispiece and 16 text figures. New York, 1932 (The University Society, 468 Fourth Ave.).—Professor Crampton states his facts in a clear, concise manner and in a form quite understandable to the average intelligent reader. He first explains the nature of life and of living things, the animals and plants, and the origin of living matter. This is followed by the meaning of evolution and the earlier views held concerning it. Next the interpretation of animal structure is discussed from the standpoints of classification, comparative anatomy, and vestigial structures. Then the facts of development as bearing on evolution are set forth by means of the frog and mammalian embryologies. The third major factor is the evidence from paleontology, which is briefly summarized. The concluding chapter is devoted to the natural processes of evolution.

The illustrations were carefully selected, and they well supplement the text. The book is ably written and of value to layman and scientist alike. M. R. THORPE.

Man and Microbes; by STANHOPE BAYNE-JONES. University of Rochester, N. Y. Pp. x, 128; 16 figs. and frontispiece. Baltimore, Md., 1932 (The Williams & Wilkins Company, $1.00).—This small volume, attractively printed and bound in a form that readily slips into one's coat pocket, may well serve as a model for the "Century of Progress Series" to which it belongs. The translation of the results of scientific research into a story that will be appealing to the layman is admittedly one of the difficulties that confront investigators everywhere. Professor Bayne-Jones, himself an accomplished bacteriologist, has succeeded in a delightful way in presenting the history of the microbiology so that any intelligent reader can gain an appreciation of the place of the lowliest organisms in nature and their manifold relations to man and his environment. Something of the pleasing style and fascinating diction of the nine brief essays that comprise the book may be gained from a few illustrative quotations. We are reminded that "the microbiologist works in the midst of steam, blue gas flames, hot wires, cotton plugs, appetizing smells, foul odors, jewel-like lenses, bright spot-lights, brilliant colors, patient animals, long words and the smallest specks of life." In the chapter on "Microbes and Insects," we are told that "it seems certain that as knowledge increases, man will make increasing use of bacterial bullets in his warfare against the insect pests." The common sharing of microbes by man and animals brings dangers; so that "indeed, microbes, more crafty than the Greeks at Troy, steal into the citadel of human health, not only in the body of a horse, but also in the bodies of nearly all the animals." The reader is left with the assurance that "microbes are the masters of man." It seems fair to say, however, that microbiology has been one of the most liberating of influences, because "in removing the fear of the supernatural in disease it removed a superstitious dread from daily life. The study of microbes has shown man how he, by his own rational efforts, can control at least a part of his destiny." Few books that depict the intellectual endeavor of the past century surpass these little essays by Bayne-Jones in inherent charm and interest. L. B. M.

Illustrations of Japanese Aquatic Animals and Plants. In two volumes with English and Japanese text and many plates.—This important work, issued by the Fisheries Society of Japan, is also published in this country by the Stanford University Press. Volume I includes the Animals, Volume II the Plants. Each species is clearly described in English as well as Japanese. The colored plates are especially remarkable, both for the accuracy of the drawing and the beauty of the coloring. In the case of the fishes, for example, the effect of the scales is brought out by sprinkling the varnished surface with silver dust (or mica).

The volumes are 20½ by 14½ inches over all, bound in brown cloth tied with white silk cord and with pasted leather label. The set may be purchased for $50 net, post paid.

PUBLICATIONS RECENTLY RECEIVED

Geology of the Country south of Piet Retief with Explanation of Sheet 68; by W. A. Humphrey and L. J. Krige. Pretoria, 1931. Geological Survey, Union of South Africa (5 s. with map).

Le Calcul des Différences Finies et ses Applications; by Alfred Henry translated from English by A. Salin. Paris, 1932 (Hermann et Cie, 50 francs).

The Skycraft Book; by Laura B. Harney. Foreword by Roland H. Spaulding. Boston, 1932 (D. C. Heath & Co., $1.08).

Man & Microbes; by Stanhope Bayne-Jones. Baltimore, 1932 (Williams & Wilkins Co., $1.00).

A Preliminary Study of the Ruins of Coba, Quintana Roo, Mexico; by J. Eric Thompson, Harry E. D. Pollock, Jean Charlot. Carnegie Institution of Washington, 1932. Publication No. 424. Price $4.50 paper-bound, $5.50 cloth bound.

Principles of Soil Microbiology; by Selman A. Waksman. Second Edition Entirely Revised. Baltimore, Md., 1932 (The Williams & Wilkins Co., $10.00).

Interpolation und Genäherte Quadratur. Eine Ergänzung zu den Lehrbüchern der Differential-und Integralrechnung; by Prof. Dr. Gerhard Kowalewski. Leipzig, 1932 (Verlag von B. G. Teubner. R.M. 9.60).

Soil Conditions and Plant Growth; by Sir E. John Russell. Sixth Edition. New York, 1932 (Longmans Green and Co., $7.50).

West Virginia Geological Survey. County Reports 1931. Randolph County; by David D. Reger, Associate Geologist. James D. Sisler, State Geologist, Box 879, Morgantown, 1931, the price of the volume and case of maps is $3.00.

A Laboratory Manual of General Chemistry. (Larger Edition Revised.) Leon B. Richardson and Andrew J. Scarlett, Jr.

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The Carnegie Foundation for the Advancement of Teaching. Review of Legal Education in the United States and Canada for the Year 1931; by Alfred Z. Reed.

Canada Department of Mines. Geological Survey. Memoir 169. Geology and Mineral Deposits of a Part of Southeastern Manitoba; by J. F. Wright. Summary Report, 1930. Part D. Summary Report, 1931. Part B. Report of the Department of Mines for the Fiscal Year Ending March 31, 1931.

Handbuch der Kolloidwissenschaft in Einzeldarstellungen. Band V. Kolloidchemie der Seifen; von Dr. E. L. Lederer. Dresden, 1932 (Verlagsbuchhandlung Theodor Steinkopff, RM. 38, and RM. 39.80 bound).

Researches on Fungi; by A. H. Reginald Buller. Vol. IV. London and New York, 1931 (Longmans, Green and Co., 21s. net).

Thermionic Vacuum Tubes; by E. V. Appleton. New York, 1932 (E. P. Dutton and Company, $1.25).

Meet the Sciences; by William Marias Malisoff. Baltimore, Md., 1932 (The Williams & Wilkins Co., $2.50).

The Last Cruise of the Carnegie; by J. Harland Paul. Baltimore, Md., 1932 (The Williams & Wilkins Co., $5.00).

Wissenschaftliche Ergebnisse Der Dr. Trinkler'schen Zentralasien Expedition. Band I. Geographische Forschungen Im Westlichen Zentralasien Und Karakorum-Himalaya; by Dr. Emil Trinkler. Band II. Geologische Forschungen Im Westlichen K'Un-Lun Und Karakorum-Himalaya; by Dr. Hellmut De Terra.

Bulletin of the University of Kansas. State Geological Survey of Kansas. The Geology of Wallace County Kansas; by Mexim K. Elias.

Introductory General Chemistry; by Stuart R. Brinkley. New York, 1932 (The Macmillan Company, $3.00).

New York State Museum Bulletin. 1. The Mining and Quarry Industries of New York State for 1927 to 1929. 2. Review of the Natural Gas and Petroleum Developments in New York State; by D. H. Newland, State Geologist, and C. A. Hartnagel, Assistant State Geologist. Albany, 1932 (The University of the State of New York).

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An Introduction to Geology; by William B. Scott. Third Edition. Vol. I. Physical Geology. Vol. II. Historical Geology. New York, 1932 (Macmillan Company, Vol. I, $3.50, Vol. II, $3.00).

Riddles of Sciences; by Sir J. Arthur Thomson. New York, 1932 (Liveright, Inc., Publishers, $3.50).

OBITUARY.

DR. PORPHIRII NIKITCH KRYLOFF, professor of botany and plant geography at the University of Tomsk, died on December 27, 1931, aged eighty-one. He contributed much to the knowledge of the Siberian flora.

MR. JAMES JOHN JOICEY, British naturalist, especially interested in butterflies and moths, died early in March at the age of sixty-one years. He was a liberal benefactor of the British Natural History Museum.

Mr. **Henry Chapman Jones**, British chemist long connected with the Royal College of Science, died on March 7 at the age of seventy-seven years.

Sir Patrick Geddes, formerly professor of botany at the University College, Dundee, Scotland, died recently at the age of seventy-eight years.

Mr. **Richard South**, British entomologist, died on March 28 in his eighty-sixth year.

Dr. **James William Toumey**, of the Yale School of Forestry since its foundation in 1900, and its dean from 1910 to 1922, died on May 6 at the age of sixty-seven years. He was assistant in botany at the Michigan Agricultural College, 1890, 1891, and professor of biology at the University of Arizona, 1891 to 1898.

Dr. **Donald Ryder Dickey**, since 1926 research associate in vertebrate zoology at the California Institute of Technology, died on April 15 aged forty-five years.

Dr. **Wilfred Welday Scott**, professor of chemistry at the University of Southern California from 1925, died suddenly on May 2 aged fifty-six years.

HUGH GIBB

1860-1932

The Peabody Museum of Natural History at Yale sustained a great loss in the death of Hugh Gibb, its chief preparator, on February 28, 1932. Born in Glasgow on February 27, 1860, Gibb came to America as a boy of seven, and later became a successful foreman in a weaving mill at New Britain, Conn. Prof. Marsh of Yale, hearing of his ability, called him to the Museum in 1882 as one of his preparators of fossil skeletons, and before long Gibb came to be one of the leaders in this new technique. For fifty years he gave his best to the Museum, wherein remain, as striking monuments to his industry, skill, and art, such large mounts as the Otisville mastodon, *Brontops, Claosaurus* (the first dinosaur skeleton set up in America), *Stegosaurus, Morosaurus, Archelon,* and, last of all, the giant *Brontosaurus*. In addition, thousands of bones and hundreds of skulls were worked out of their enclosing rock by him and made ready for study by the paleontologists. The finest side of Gibb, however, was the extraordinary beauty of his character and his high ideals, making his corner of the workshop a place to which flocked students and associates alike, not only to see a master at work in the restoration of once famous creatures, but to ask counsel that was always helpful. His like will not soon be seen again.

CHARLES SCHUCHERT.

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